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# DEVELOPING A PREDATION INDEX AND EVALUATING WAYS TO REDUCE SALMONID LOSSES TO PREDATION IN THE COLUMBIA RIVER BASIN

Final Report
August 1988 - September 1990

Prepared by

Anthony A. Nigro

Oregon Department of Fish and Wildlife

Cooperators
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Prepared for

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P.O. Box 3621
Portland, OR 97208-3621

Project No. 82-012
Contract Number DE-A179-88BP92122

December 1990

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Final Report

August 1988 - September 1990

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## CONTENTS

# EXECUTIVE SUMMARY

We report our results of studies to develop a predation index and evaluate ways to reduce juvenile salmonid losses to predation in the Columbia River Basin. The study was a cooperative effort by the Oregon Department of Fish and Wildlife (ODFW), Oregon State University (OSU), and University of Washington- Fisheries Research Institute (UW-FRI) and Center for Quantitative Science (VW-CQS). ODFW was the lead agency and sub-contracted various tasks and activities to OSU, UW-FRI and VW-CQS based on expertise each brought to the study. Study objectives of each cooperator were

1. ODFW (Report A): Develop an index'to estimate predation losses of juvenile salmonids (*Oncorhynchus* spp) in reservoirs throughout the Columbia River Basin, describe the relationships among predator-caused mortality of juvenile salmonids and physical and biological variables, examine the feasibility of developing bounty, commercial or recreational fisheries on northern squawfish (*Ptychocheilus oregonensis*) and develop a plan to evaluate the efficacy of predator control fisheries.

2. OSU (Report B): Determine the economic feasibility of developing bounty and commercial fisheries for northern squawfish, assist ODFW with evaluating the economic feasibility of recreational fisheries for northern sguawfish and assess the economic feasibility of utilizing northern sguawfish, carp (*Cyprinus carpio*) and suckers (*Catostomus* spp)in multispecies fisheries.

3. UW-FRI (Report C): Evaluate commercial technology of various fishing methods for harvesting northern squawfish in Columbia River reservoirs and field test the effectiveness of selected harvesting systems, holding facilities and transportation systems.

4. VW-CQS (Report D): Modify the existing Columbia River Ecosystem Model (CREM) to include processes necessary to evaluate effects of removing northern sguawfish on their population size structure and abundance, document the ecological processes, mathematical equations and computer (FORTRAN) programming of the revised version of CREM and conduct systematic analyses of various predator removal scenarios, using revised CREM to generate the simulations.

Background and rationale for the study can be found in our 1989 annual progress report on the study (Vigg and Burley 1989- see References section in Report A).

Highlights of results of our work by report are

## Report A

1. Our bootstrap analyses of catch per unit effort (CPUE) based indices of relative abundance indicated that each of six techniques considered had a 90 percent probability of estimating a parametric mean CPUE within ± 50 percent. This was within the order of magnitude criteria established by Pacific Northwest regional managers for determining that a predator

abundance index is feasible and useful for measuring the relative magnitude of predation losses among reservoirs in the Columbia and Snake rivers. Two of the indices, percent zero catches and natural logarithm of non-zero catches, had a 90 percent probability of measuring a parametric mean CPUE within ± 15 percent.

2. Optimum sample size for achieving high probabilities (>90 percent) of precisely (+ 15 percent) measuring a parametric mean CPUE was approximately 12 replicates. When considered within the context of a sampling design similar to that used in our baseline reference study in John Day Reservoir, i.e. three areas and two time periods per reservoir annually, 12 replicates per area-time period strata are logistically feasible using two gill net and two electrofishing boats and crews.

3. Examination of northern squawfish fecundity for use in estimating the reproductive potential of northern sguawfish populations showed considerable variation in fecundity-size relations. However, fecundity varied directly with total weight; 'fecundity = 76.4 (total weight)$^{0.95}$.

4. Year-class strength indices for northern sguawfish and walleye correlated well with theoretical initial population sizes when the population structure reflected random recruitment. However, when population structure reflected decreasing or increasing trends in recruitment, the indices were less robust, especially if less than seven years of catch data was used in analyses.

5. We precisely aged northern sguawfish using scale samples, but a question remains about the accuracy of the ages. The average percent error was 7.4 percent and the coefficient of variation was 0.10.

## Report B

1. Organic and heavy metal contaminant testing indicated PCB chlordane, DDT derivatives, mercury, aluminum, lead and arsenic levels in northern sguawfish fillets and organs were within Food and Drug Administration action levels (where they exist). Samples were not tested for dioxin or radioactivity.

2. Tests in five Vietnamese, Chinese, and American restaurants and five Vietnamese markets showed northern squawfish were easy to handle and prepare and had good quality flesh. Steamed, fried or sauteed dishes were priced from $5.60 to $7.50 in restaurants. Whole, uncleaned northern squawfish in markets were priced from $0.29 to $0.99 per pound. All participating restaurants and markets cited unfamiliarity with the product and its boniness as market problems. Several owners were willing to market a de-boned product.

3. Frozen northern squawfish provided to a fish buyer and to a multiple-use processing plant were favorably received by both. The fish buyer marketed samples as crayfish bait and received $0.10 per pound. The multiple-use processing plant used samples in an enzyme hydrolysate process and produced a liquid base for organic fertilizer.

4. Live and iced northern squawfish transported well to restaurants and markets. The only problem was cosmetic, i.e. fish dead for a day upon delivery had a mottled skin color although flesh quality was not affected. Iced fish brought the same price as live fish, suggesting the extra cost of transporting fish live was not cost-effective.

5. We developed a questionnaire for regulatory review containing questions about issues to be addressed prior to development of any fishery for northern sguawfish other than the existing recreationa'l fishery. Plan5 to mail the questionnaire to entities within whose jurisdiction fishery activities would fall were outlined for Pacific Northwest regional managers to pursue as various new fisheries are considered for implementation.

## Report C

1. We considered seven gear types as potential candidates for field testing based on several criteria including 1) their adaptability to commercial vessels of the sizes and types generally used in the Columbia River Basin, 2) their suitability to the physical environment of Columbia River Basin reservoirs, 3) whether they had already been extensively tested in the Columbia River Basin, 4) the quality of northern sguawfish captured, and 5) the occurrence of incidental catch. The gear types considered were a purse seine, baited long-lines, a beach seine, baited pots, set gill nets, drift gill nets, and a trap net. Based on the criteria used, we selected the purse seine and baited long-lines as potentially effective, relatively untested, gear types that warranted further intensive field testing. We also selected a beach seine, baited pots, set gill nets and drift gill nets for limited field testing under specific conditions.

2. We evaluated effectiveness of gear types tested by considering its catch per unit effort (CPUE) of northern squawfish, its incidental catch of species other than northern squawfish, and the ease with which it was deployed.

3. We caught 92 northern squawfish in 52 purse seine sets, for an average catch per set of 1.8. Northern squawfish comprised 42 percent of all species caught. Sets took an average of 20 minutes to complete. American shad comprised about 43 percent of the incidental catch; 54 shad were caught. Other species caught (numbers in parentheses) were catostomids (31), carp (15), steelhead (11) chinook salmon (9), sockeye salmon (3), chiselmouth (3) and walleye (1).

4. We caught 525 northern sguawfish in 115 sets of baited long-lines (about 55 hooks per line and about 5.5 hours per set) from April through August. This averaged out to about 5 squawfish per long-line set. About 72 percent of catch was northern squawfish. Mher species caught (numbers in parentheses) were white sturgeon (83), channel catfish (81), cottids (14), yellow perch (8), bullheads (7), catostomids (4), American shad (2), and carp (2). In 82 long-line sets, from September through November, we captured 129 northern sguawfish, or less than 2 squawfish per long-line set. About 46 percent of the incidental catch was channel catfish; 41 channel catfish were caught. White sturgeon accounted for 20 percent of the incidental catch during this fall period. Comparisons of different baits fished from long-lines in September through November indicated

highest CPUE of northern squawfish using young-of-the-year American shad as bait; about 17 hooks per fish caught. CPUE of northern sguawfish using juvenile salmonids as bait averaged about 21 hooks per fish caught, which was about one-third the CPUE in June through August. Northern sguawfish were also caught using crayfish, small cottids and nightcrawlers as bait, however CPUE ranged from 32 to 80 hooks per fish caught. No northern sguawfish were caught using herring, suckers or trout perch as bait. We compared hook types used with long-lines based on four criteria; CPUE of northern squawfish, ease of handling and baiting, ease of removal from fish, and ease of maintenance (keeping the hook sharp and unbent). A 3/0 Kahle (English Bait) horizontal hook appeared to be the best hook based on the criteria. Hook loss rate was approximately 4.5 percent.

5. We made 175 bottom gill net sets and caught 136 northern squawfish. Average soak time per bottom gill net was 2.4 hours and average CPUE of northern sguawfish was 0.3 per hour. We caught no northern sguawfish in two drift gill net sets, but did catch 9 northern squawfish in 27 surface gill net sets. CPUE of northern squawfish in surface gill nets averaged 0.1 per hour. Incidental catch in bottom gill nets was high; some of the other fish species we caught were: 542 catastomids, 76 American shad, 56 white sturgeon, 45 channel catfish, 14 walleye, 11 smallmouth bass, 10 steelhead and 5 salmon.

6. Twenty northern sguawfish, over half of which were under 250 mm in length, were caught in 37 baited pot sets, one 48-hour trap net set and 8 beach seine hauls. Incidental catches by each gear exceeded catch of northern squawfish.

7. Two of 40 white sturgeon (5%) and 3 of 22 catfish (13.6%) caught by long-lines from April through August and held in pens in the river died; all in the first day of holding and most from bleeding from removal of swallowed hooks. Similar tests held from September through November showed no deaths among 10 white sturgeon and only 1 death among 16 channel catfish. Some mortality of fish caught with bottom gill nets was observed; five of nine steelhead died and many American shad appeared to be moribund. Also six walleye were killed in one overnight set and many channel catfish and suckers were injured while being removed from nets.

8. Comparisons among gear showed long-lines required the least investment and handling time and had the lowest incidential catch and mortality of incidentally caught fish species. Long-lines also caught the most northern squawfish. A potential problem with long-lines is conflict with recreational gear. However, northern squawfish were caught throughout the water column suggesting that depths-of-set can be adjusted and long-lines effectively marked with buoys to minimize conflict with recreational anglers.

## Report D

1. We documented the Columbia River Ecosystem Model (CREM), a differential equation model and associated computer simulation program, and used it to Project mortality of juvenile salmonids caused by complex interactions occurring during downstream migration.

2. We modified CREM to consider effects on juvenile.salmonid mortality of 1) a reduction of the predator population, 2) dynamically variable population distribution 'throughout the reservoir, and 3) population dynamics and growth in response to ingested food (energetics) of predator populations. We also modified CREM to calculate 1) error bounds or confidence limits on predicted juvenile salmonid mortalities due to stochastic variation or uncertainty in model parameter values and driving functions, 2) projections of juvenile salmonid mortalities over multiple years, and 3) projections of juvenile salmonid mortalities over a system of connected reservoirs, rather than a single reservoir.

3. We simulated juvenile salmonid mortality caused by northern squawfish predation by reservoir area (tailrace, reservoir, channel, nearshore, and forebay) and salmonid type (age-0 chinook, age-l chinook, steelhead, coho, and sockeye). Simulations were performed for 1985 conditions in John Day Reservoir. Total mortality estimates ranged from 0.123 for age-l chinook to 0.597 for age-0 chinook.

4. Daily passage levels of at least twice the level estimated for 1985 in John Day Reservoir were used to simulate conditions when prey densities were above the inflection point of the functional response curve (i.e. were at levels where predators were "swamped). As daily passage was increased from 2X to 4X the 1985 level, predation loss increased by about 27 percent. However, predation mortality decreased 30 percent.

5. Mean residence times were varied from 7 to 134 days to examine response of predation loss and mortality to increasing residence time. Predation losses and mortality almost doubled when residence times were increased from 7 to 18 days. Predation losses and mortality increased 2.5X when mean residence time increased from 7 to 134 days.

6. Comparisons of predation losses and mortality at northern squawfish abundances of 1.0, 0.5 and 0.1 times 1985 levels in John Day Reservoir indicated non-proportional survival. Survival was non-proportional because although fewer predators resulted in higher prey densities, the rate of change in consumption slowed at very high prey densities.

7. As water temperatures increased, so did predation losses and mortality, up to 21.5 C. At temperatures greater than 21.5 C, consumption by northern squawfish, and thus mortality, decreased.

REPORT A.

# Developing a Predation Index and Evaluating Ways to Reduce Juvenile Salmonid Losses to Predation in the Columbia River Basin

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## CONTENTS

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## ABSTRACT

We are reporting progress on the predator-prey study for the period August 28, 1988 to September 1, 1990. The purposes of this research are to evaluate the feasibility of an index for assessment of predation in various reservoirs throughout the Columbia River basin, to describe the relationships among predator-caused mortality of smolts and physical and biological variables; to examine the feasibility of developing bounty, commercial or recreational fisheries on northern sguawfish (*Ptychocheilus oregonensis*); and to develop a plan to evaluate the efficacy of predator control fisheries. This parent project has three sub-components, presented separately in Reports B (Hanna 1990), C (Mathews *et al.* 1990) and D (Bledsoe 1990) of this volume.

In the 1989 Annual Progress Report we completed several tasks (Vigg and Burley 1989): (1) literature searches on predator abundance indexing and factors regulating fish population dynamics were conducted; (2) selected references were summarized, and compiled in a key-word bibliography format; (3) the feasibility of various types of predator abundance indices was assessed; (4) existing data relevant to mark-recapture, catch per unit effort (CPUE), physical and chemical variables, and reservoir morphology were compiled, reviewed, and summarized; (5) where sufficient data existed, preliminary implementation of predator abundance indices was demonstrated; (6) field sampling in John Day Reservoir was conducted during May to August, 1989 and the results summarized; (7) computer spreadsheets were developed to evaluate methods for year-class strength determinations of northern sguawfish and walleyes (*Stizostedion vitreum vitreum*) using restricted sampling; (8) a manuscript was submitted for publication in a fisheries journal on temperature dependent maximum consumption rates of northern squawfish (Vigg and Burley In Press); (9) a draft plan was developed for northern squawfish predator control fishery implementation and evaluation -- which has since been revised and funded as Bonneville Power Administration Project 90-077.

In this 1990 Final Report, we are reporting on the remaining tasks: (1) a statistical evaluation of the Predator Abundance Index approach using measures of CPUE; (2) quantification of a fecundity-size relation for northern squawfish; (3) an evaluation of year-class strength estimation methodologies for northern squawfish and walleyes; and (4) analysis of the precision of age determinations of northern squawfish using scales. We concluded that it is feasible to use various measures of CPUE as indices of the relative abundance of northern squawfish in Columbia River reservoirs based on the 1984-1986 data base from John Day Reservoir. Given the sampling design stratified by three reservoir areas and two time periods (12 samples per cell) -- mean CPUE of both electrofisher and gill net samples is an adequate method to assess fish relative abundance. Based on an empirical "bootstrap" analysis of the relationship between the accuracy of the index (percent difference between the Index CPUE estimate and the parametric CPUE value) versus the empirical probability of achieving that accuracy

(number of time5 out of 100 trials), we selected the Index-O {square root of relative frequency of zero catches; Bannerot and Austin (1983)) and the mean of the log of non-zero catches as the most sensitive indices of relative predator abundance based on CPUE data. A sample of 54 female northern squawfish collected from John Day Reservoir during June-July 1989 had the following biological characteristics (mean values): fork length, 398.5 mm; weight, 901.4 g; ovary weight, 93.4 g; GSI, 9.8%; fecundity, 50,521 eggs; and egg diameter, 1.20 mm. Of three methods tested for estimating relative year-class strengths of northern squawfish and walleye, the *Rieman Method* correlated the best overall with the random theoretical population structure given the assumptions of the analysis. Northern sguawfish can be aged with precision greater than 90% using scales as the aging structure. Northern sguawfish caught in bottom gill nets in John Day Reservoir during May-August 1989 ranged 4-14 years of age with a mean of 7.3 years.

## INTRODUCTION

The ultimate goal of this project is to reduce the mortality of juvenile salmonids (*Oncorhynchus* spp.) out-migrating through Columbia River reservoirs by reducing predation by northern squawfish (*Ptychocheilus oregonensis*). Mortality of juvenile salmon and steelhead migrating downstream through the Columbia River system is a major concern of the Columbia Basin Fish and Wildlife Program (NPPC 1987). As outlined in the program, mortality of juvenile salmonids occurring within mainstem reservoirs is an area of emphasis for Bonneville Power Administration (BPA) funding, and northern sguawfish predation is an important component of this "reservoir mortality". The technical work group (TWG) on Reservoir Mortality/Water Budget Effectiveness has supported continued research and implementation of control measures to help alleviate the predation problem. Predation research is over-seen by the various agencies and tribes in the Columbia River Basin through the Fisheries Passage Advisory Committee (FPAC). Direct research coordination on this project is maintained with a companion study being conducted by the U.S. Fish and Wildlife Service (Project 82-003) and three subcontractors (University of Washington, Oregon State University, and Computer Sciences Corporation). In the 1989 Annual Progress Report, we present a detailed summary of the relationship of this Project to the Columbia Basin Fish and Wildlife Program, the research background, rationale, and coordination with other agencies (Vigg and Burley 1989).

Modeling simulations of reservoir-wide potential predation in John Day Reservoir indicated that a 10-20% sustained exploitation of the northern squawfish population by a fishery could reduce juvenile salmonid losses to predation about 50% over a 5 to 10 year period (Rieman and Beamesderfer 1990). These simulation results lead to the development of a hypothesis that through harvest management of northern sguawfish, using sustained fisheries throughout the Columbia River Basin, predation mortality could be substantially reduced. A corollary to this hypothesis is that eradication of northern sguawfish is not necessary to achieve the goal of salmon and steelhead enhancement.

With the exception of John Day Reservoir, the significance and dynamics of resident fish predation are still poorly understood in the Columbia River basin. Information is needed to estimate the relative importance of predation by northern sguawfish throughout the mid and lower Columbia River and lower Snake River reservoirs, and determine if and where predation control measures should be applied. Development of a rapid assessment "Predation Index" will provide a relatively low-cost method to determine if the magnitude of fish predation in other Columbia River basin reservoirs is similar to that in John Day Reservoir. Ongoing development of predator-prey modeling will help us to understand the dynamics of system-wide predation and predict possible consequences of predator removal. A plan is necessary for the orderly development of commercial, sport, or bounty fisheries on northern squawfish throughout the Columbia River Basin. Development of a plan to evaluate the efficacy of predator control fisheries is essential for scientific management. This research project will provide the foundation for system-wide predation indexing and a comprehensive predator control program.

The specific objectives of this study are: (1) to develop an index that can be used to estimate predation losses of smolts in various reservoirs throughout the Columbia River basin; (2) to describe the relationships among predator-caused mortality of smolts and physical and biological variables; (3) to examine the feasibility of developing bounty, commercial or recreational fisheries on northern squawfish, and (4) to develop a plan for the evaluation of the efficacy of predator control fisheries (upgraded from Task 3.4, BPA-ODFW contract). A detailed list of objectives and tasks were presented by Vigg and Burley (1989).

## METHODS

### Predator Abundance Index

Conceptually, the predation index (PI) is the product of a predator abundance component (A) and a consumption index (C):

(1) $$PI= \ .C$$

We (ODFW) are evaluating the feasibility and developing the methodology for A, and the U.S. Fish and Wildlife Service (Poe and Nelson 1988) is developing C.

In the Predator Control Project 90-077 Statement of Work, we proposed a sampling design for boat sampling (electroshocking, ES; and gill netting, GN) based on (a) obtaining a representative temporal-spatial sample, (b) obtaining sufficient fish specimens for baseline biological data, (c) obtaining sufficient catch per unit effort (CPUE) samples for Predation Indexing, and (d) the amount of effort, boats, and personnel that would be logistically feasible. The sampling design we proposed was 3 areas, 2 times, and a minimum of 12 replicates per cell for each of two sampling methods (GN and ES) for each reservoir (Table A-l). The reservoir and additional tailraces proposed for sampling were

Table A-l. Predator abundance indexing sampling design, number of replicates for both electrofiohing and gill netting.

| TIME | LOCATION | | |
|---|---|---|---|
| | Forebay | Mid-Reservoir | Tailrace |
| Early (4/1 to 6/15) | 12 (2 days) | 12 (2 days) | 12 (2 days) |
| Late (6/16 to 8/31) | 12 (2 days) | 12 (2 days) | 12 (2 days) |

Bonneville, The Dalles, John Day, and McNary reservoirs, and Bonneville and Ice Harbor Tailraces. The minimum target of 56 total samples (12 replicates per cell, 3 areas in each reservoir and 1 area in each tailrace) was what we thought was logistically feasible with two gill net and two electrofishing boats and crews -- within the time constraint of the April-August smolt out-migration period.

A "bootstrap" empirical analysis was conducted on the 1984-1986 gill net (n= 2,351) and electroshocker (n= 2,931) data bases. The index values of these large data bases are considered to be the overall Or parametric CPUE value ($\mu$). The data sets were randomly sampled within the constraints of the sampling design for 200 iterations. We defined the accuracy of the estimate as the percent difference of the sample mean from the parametric mean {PD= $(|\hat{u} - \mu|/\mu)\cdot 100$}. The number of times out of a hundred trials (or % of iterations) that the sample index was less than or equal to a given percent difference from the parametric index value ($\mu \pm$ PD) is the probability of achieving that accuracy. This method is analogous to a two-tailed statistical test of the sample mean equaling the parametric mean within a given accuracy range (null hypothesis, $H_O$: $\hat{u} = \mu \pm$ PD). The probability of achieving a given percent difference would be analogous to (l-P), where P is defined (in the statistical sense) as the probability of rejecting a true null hypothesis (Type I error).

The CPUE indices evaluated were (1) percent of zero catches, (2) index of zero catches {square root of relative frequency of zero catches; Bannerot and Austin (1983)}, (3) mean of all catches, c (4) natural logarithm of the catches, LN(c), (5) mean of non-zero catches, non-O, (6) LN(non-0). Computer programs were written in BASIC to perform the analyses; the procedure is outlined in Figure A-l.

## Fecundity-Size Relation

Northern squawfish gonad samples (n= 54) were collected from the Columbia River, John Day Reservoir. The study site was described by Vigg and Burley (1989). Gonad samples were collected just prior to spawning (6 June to 7 July). The following data were recorded for each fish: collection date, time, location, fork length (mm), total weight (g) of the fish, scale sample, sex, and gonad weight (g).

Gonads were removed from 54 female fish, and placed in plastic bags with labels and kept on ice. In the laboratory, fresh gonads were weighed to the nearest 0.1 g using a dial-o-gram balance, After weighing, female gonads were placed in jars and preserved in Gilson's solution for later fecundity determinations, Male gonad weights were recorded and the testes were disposed of,

Fecundity was estimated by a gravimetric method similar to that of Wolfert (1969). The ovaries from 54 northern squawfish were stratified by 25-mm length increments and used for fecundity analysis, Gilson's solution was drained from the ovary samples through a sieve (0.333 and O-270 mm) that had been pre-weighed and tared on a Mettler PC 180 scale. The eggs were rinsed with water to

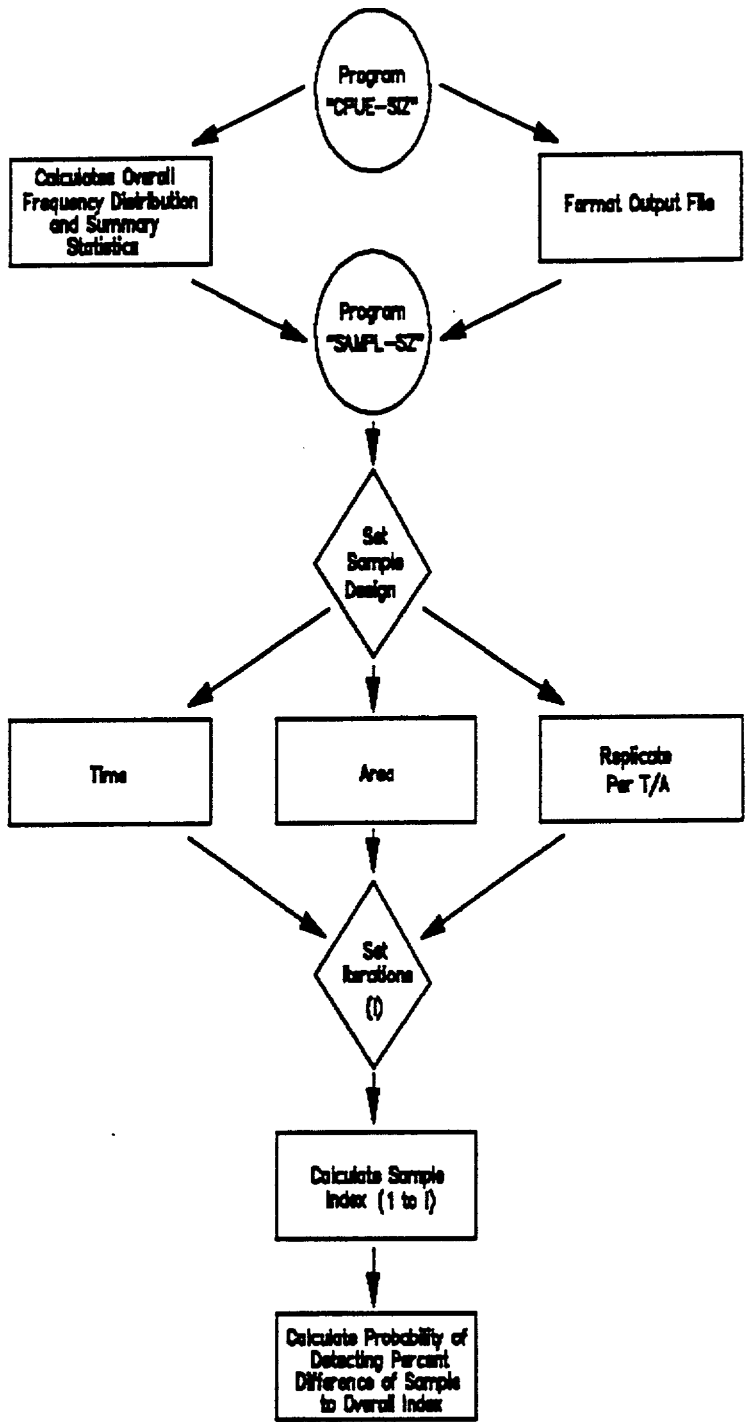


Figure A-1. Flow chart for using Programs 'CPUE-SZ' and 'SAMPL-SZ' to perform a bootstrap analysis of probabilities of detecting percent differences between CPUE indices based on a specified sampling design versus the overall (parametric) value.

remove any remaining preservative. After rinsing, all excess tissue was removed from the sample. Any eggs remaining clumped together were separated. The sieve was wiped dry with paper towels and the screen was blotted from the underside to draw off excess water from the eggs. The sample was then weighed (± 0.001 g) and recorded. Three subsamples of randomly mixed eggs were removed and weighed (± 0.001 g). A subsample containing ≈ 200 eggs was estimated for the subsample amount (weights varied among samples according to egg size). Each subsample was counted and the numbers recorded. Total numbers of eggs were calculated by direct proportion for both subsample ($F_s$) and overall ($F$) fecundity estimates:

(2) $$F_s = \frac{W_t \cdot N_i}{W_i}, \text{ and}$$

(3) $$F = \frac{W_t \cdot \Sigma N_i}{\Sigma W_i},$$

where, $W_t$= total gonad weight (preserved), $W_i$= weight of subsample, $N_i$= number of eggs counted in subsample, and $_i$= 1 to 3.

Egg diameter (± 0.01 mm) was measured for each fish using a Bausch & Lomb Zoom 5 microscope with ocular micrometer. Five eggs from each of 3 subsamples per fish were measured in ocular units under a microscope, using a 1.5 zoom setting, then converted to millimeters (1 ocular unit= 0.06 mm). The mean egg diameter ($D_m$) for each fish was calculated:

(4) $$D_m = \frac{\Sigma Di}{15},$$

where, $D_i$= diameter of an individual egg (mm), and $_i$= 1 to 15.

Gonadal Somatic Index (GSI) was determined using the total weight of the fish ($W_t$) measured in the field prior to gonad removal, and gonad weight ($W_g$) measured fresh in the laboratory (± 0.1 g). GSI was calculated as:

(5) $$GSI = \frac{W_g \cdot 100}{W_t}$$

The relationships between fish length and weight, fish size and fecundity, and fresh versus preserved ovary weights were determined by least squares regression. Descriptive statistics (e.g., mean and variance) and frequency distributions were also calculated for each variable. StatGraphics and SuperCalc software were used for computer data analysis.

### Year-class Strength Estimation Methodology

A selective review of the available literature related to year-class strengths was conducted. Of the literature reviewed, those methods that used catch per unit effort as the primary data to estimate year-class strengths were considered for-inclusion in our analyses.

The methods for analyzing year-class strengths compared were: the El-Zarka method (1959), the Extrapolation of cohort regression, modified from Gulland (1983), and the Rieman method (Rieman and Beamesderfer 1988). A series of computer programs were developed to test the selected methods for estimating relative year-class strengths using basic catch data: numbers of fish caught, and age of fish at capture. We tested two general fish life history scenarios -- one, a fish species that is recruited to the gear at age five and lives to be fourteen (e.g., northern sguawfish), and the other, a fish species that is recruited to the gear at age two and lives to be seven (e.g., walleye). We systematically varied the input variables: population size, and number of consecutive years data were collected. The effects of population structure were tested using three scenarios for northern sguawfish life history (Figure A-2) and walleye life-history (Figure A-3); we assumed the maximum population size for northern sguawfish was ten times higher than that for walleyes, i.e., 1 million versus 100,000. The continuous time series of catch data was tested at 3, 7, and 11 years. For this analysis we simplified the population dynamics that would be seen in the actual ecosystem in an attempt to isolate the variables tested. We used a combination of both theoretical and empirical values for age specific mortality rates in the analysis. The mortality values for age zero to age 5 northern sguawfish were derived from a theoretical regression line. The regression line was constructed by first determining the theoretical number of age zero fish that would be produced (average fecundity multiplied by total spawning fish). This value was used as the Y-intercept (number of fish at age zero). Then through successive iterations, an exponential decreasing line was plotted from this point through age eight to obtain instantaneous mortality estimates for each age group (Dr. Sam Bledsoe, Computer Sciences Corporation, Personal Communication). We used the instantaneous mortality values derived from this regression for age zero to age five fish. We used the values of age zero to age two from this regression for the walleye life history scenario also. The instantaneous mortality estimates for northern squawfish after age 5 were taken from Beamesderfer *et al.* (1987, Table 5). We chose to disregard the outlier mortality estimates of the age 7-8, 10-11, and 12-13, and averaged the remaining estimates to get a mean mortality estimate of 0.15. For walleye, we chose to use the data after age 2 from Beamesderfer et *al.* (1987, Table 12) to calculate a linear regression on these data to obtain the instantaneous mortality values for each age group. A listing of the variables held constant during the relative year-class strengths analysis are presented in Table A-2. We tested each method using simple

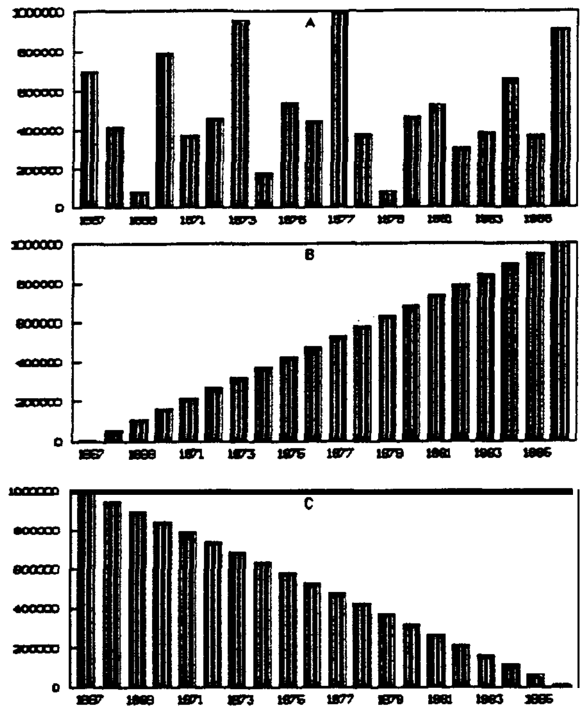


Figure A-2. Number of northern squawfish at age zero for year-class strength analysis. A= random population fluctuation between 10,000 and 1,000,000, B= increasing population trend, and C= a decreasing population trend.

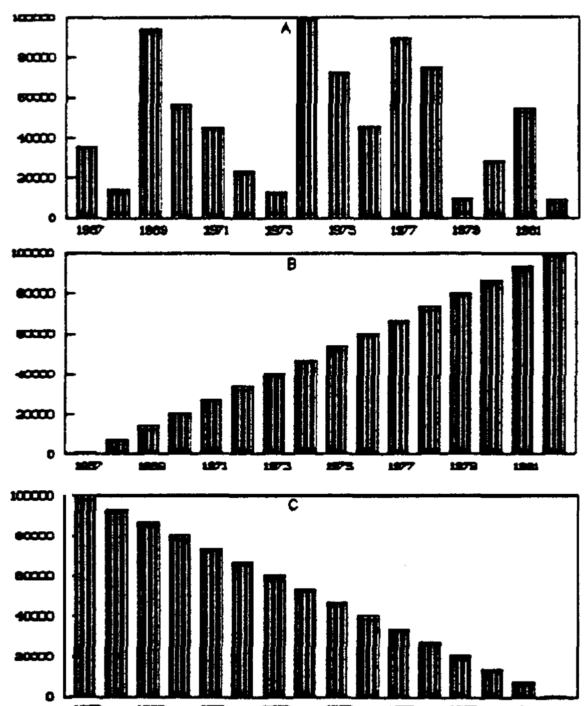


Figure A-3. Number of walleye at age zero for year-class strength analysis. A= random population fluctuation between 1,000 and 100,000, B= increasing population trend, and C= a decreasing population trend.

Table A-2. Potential variables held constant for relative year-class strength analysis.

(1) The total sampling effort for each year was constant.

(2) The sample size for each year was constant.

(3) Catchability was constant for each age group through time.

(4) We assumed no missing data for any age group in our catch samples.

(5) Age specific mortality was determined using a combination of theoretical and empirical values.

(6) There was no stochasticity in the design of the test (i.e., there was no random variability around the variables in the computer programs).

correlation analysis to determine the ability of the method to predict the year-class structure of the theoretical population. Below is a brief summary of the methods chosen for review in this analysis. The assumptions of each of these methods are listed in Table A-3.

Table A-3. Assumptions of three year-class strength methods reviewed.

| Assumption | Method |
|---|---|
| (1) A standard sampling design was used both spatially and temporally. | a, b, c |
| (2) The effort was standardized for comparison between years. | a, b, c |
| (2) All age groups were fully recruited to the gear. | b, c |
| (3) Age specific mortality was constant for age groups represented in the sample. | a, b, c |
| (4) Age groups were the same between a year-class and the previous year-class compared. | a |
| (5) Age specific catchability was constant between years. | a, b, c |

a. El-Zarka
b. Extrapolation
c. Rieman

The El-Zarka (1959) method is an adaptation of the method used by Hile (1941) to estimate annual fluctuations in growth rate. El-Zarka (1959) used the adapted "Hile" method to assess the year-class strengths of yellow perch, *Perca flavescens* (Mitchill), in Saginaw Bay, Lake Huron. The procedure was based on a series of comparisons in which the abundance of each year-class was estimated in terms of the strength of the preceding one. Fish were collected each year using commercial trap nets, fyke nets, and other gear (a minor percentage). All the fish used for year-class strength analysis were aged and came from the samples collected during May or early June. The data were arranged into a table by capture date and year-class. Each year-class strength was estimated by comparing the age groups represented in that year-class with the same age groups represented in the preceding year-class. The first year-class data is given an arbitrary value of zero, and subsequent year-classes are determined by the successive addition of the percentage difference. The percentage difference is then subtracted from the mean percent difference to arrive at the relative year-class strength index.

In "Fish Stock Assessment: a Manual of Basic Methods", by J.A. Gulland (1983); A method to estimate mortality rates using catch of the same year-class (cohort of fish in successive years) is discussed. Given certain assumptions, the relative year-class strength could be estimated by extrapolation back to the y-axis. Here defined as the Extrapolation Method. The procedure uses CPUE data for individual year-classes plotted on a logarithmic scale against age, The CPUE at age zero can be read from this graph, back transformed to an arithmetic mean, standardized to 100, and then used as the index for between year-class comparisons.

The Rieman method (Rieman 1987) used a regression approach to estimate relative year-class strengths from annual catch curves. A mortality estimate was made using a linear regression (log, number of fish vs age of the fish) with all years of catch curve data combined. The residuals of the catch data were calculated. These residuals were back transformed to an arithmetic scale, standardized to a mean of zero, and the standardized mean residual value for each year-class was used as the index:

(6) $$\text{Index} = e^{(\ln Nd - \ln Np)}.$$

where Nd is the individual data point and Np is the predicted value using the derived equation:

(7) $$\ln(Np) = b + m(A).$$

where A is the age of the fish, b is the y intercept, and m is the mortality estimate.

## Age Determination Precision

Final age determinations were made for northern squawfish caught in bottom gill nets (n= 102) by aging the entire group three times and taking the average age for each fish. We tested for differences in the means of the first aging (n= 108) which appears in Vigg and Burley (1989) with the final aging using the t test. No further analysis was conducted on the walleye aging due to a small sample size (n= 13) Vigg and Burley (1989).

Precision estimates of aging northern sguawfish scales were completed using the methods of Chang (1982). The reader aged the scale samples (n= 153) three times independently. The average percent error (APE), Equation 8, and the coefficient of variation (CV), Equation 9, were used as indices to describe the reproducibility of age determinations.

$$\text{(8)} \qquad APE = \frac{1}{R} \sum_{i=1}^{R} \frac{|Xij - Xj|}{Xj} \cdot 100$$

Where Xij is the ith age measurement of the jth fish, Xj is the mean age of the jth fish and R is the number of time the jth fish was aged.

$$\text{(9)} \qquad CV = \frac{SD}{Xj}$$

Where SD is the sample standard deviation.

# RESULTS

## Predator Abundance Index

Catch per unit effort (CPUE) of northern sguawfish from gill net samples for the combined 1984-86 data base have a skewed (negative binomial) distribution with 38.6% zero catches, a mean of 1.65 fish per hour, and a variance of 5.76 (Figure A-4). The combined CPUE data from boat electroshockers during 1984-86 had an even more skewed distribution than that of gill nets (Figure A-5). The electroshocking data had 63.9% zero catches, a mean of 1.17 northern sguawfish per 15-minute transect, and a variance of 11.74. In contrast, by sampling the "population" of CPUE data with the "bootstrap" procedure, i.e., with 200 random iterations of the proposed sampling design -- a relatively normal distribution of catches was achieved for both the gill net (Figure A-6) and electrofishing (Figure A-7) data sets. The mean of the "bootstrap"

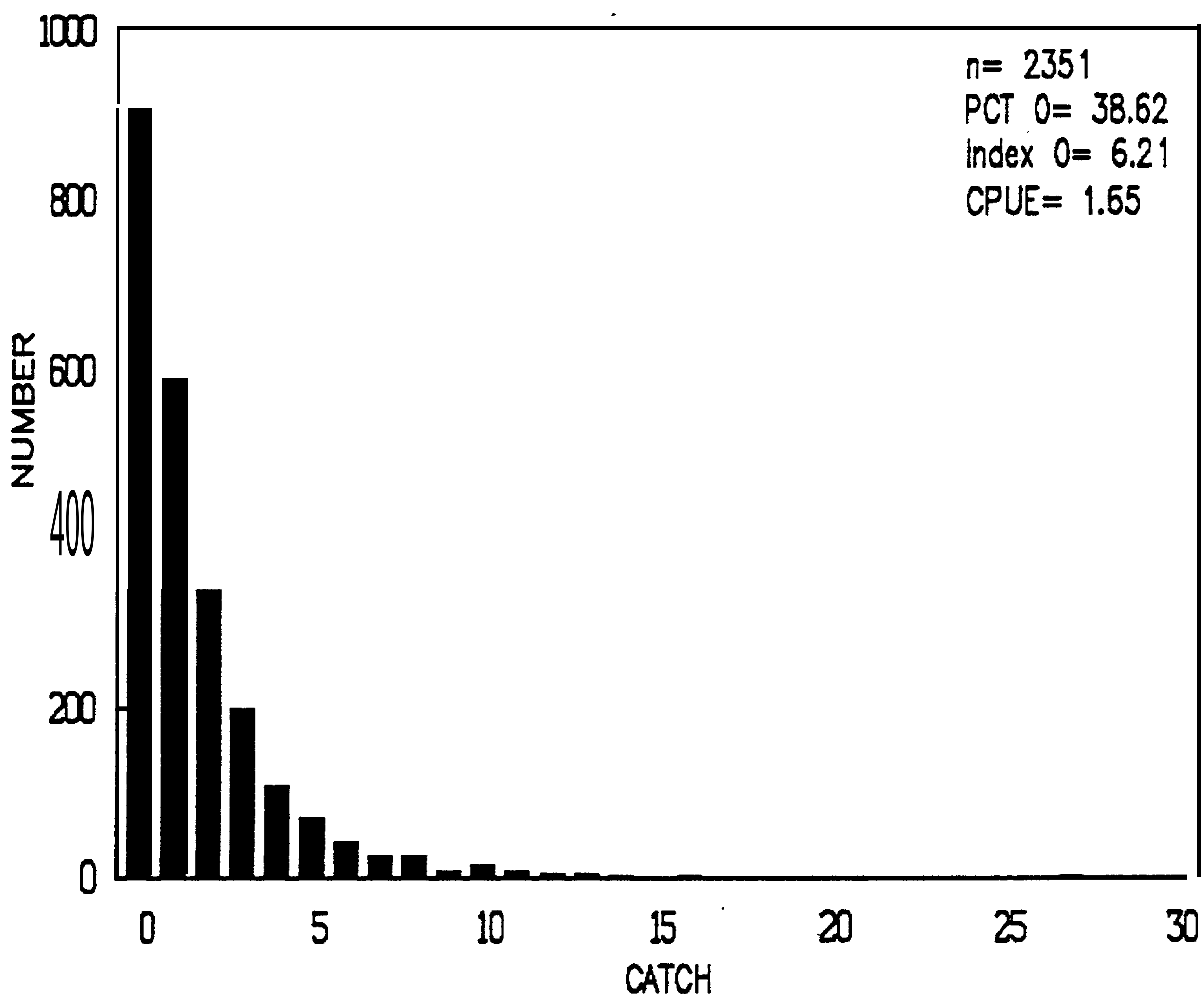


Figure A-4. Frequency distribution of bottom-set gill net catches (raw data) in John Day Reservoir during 1984-1986.

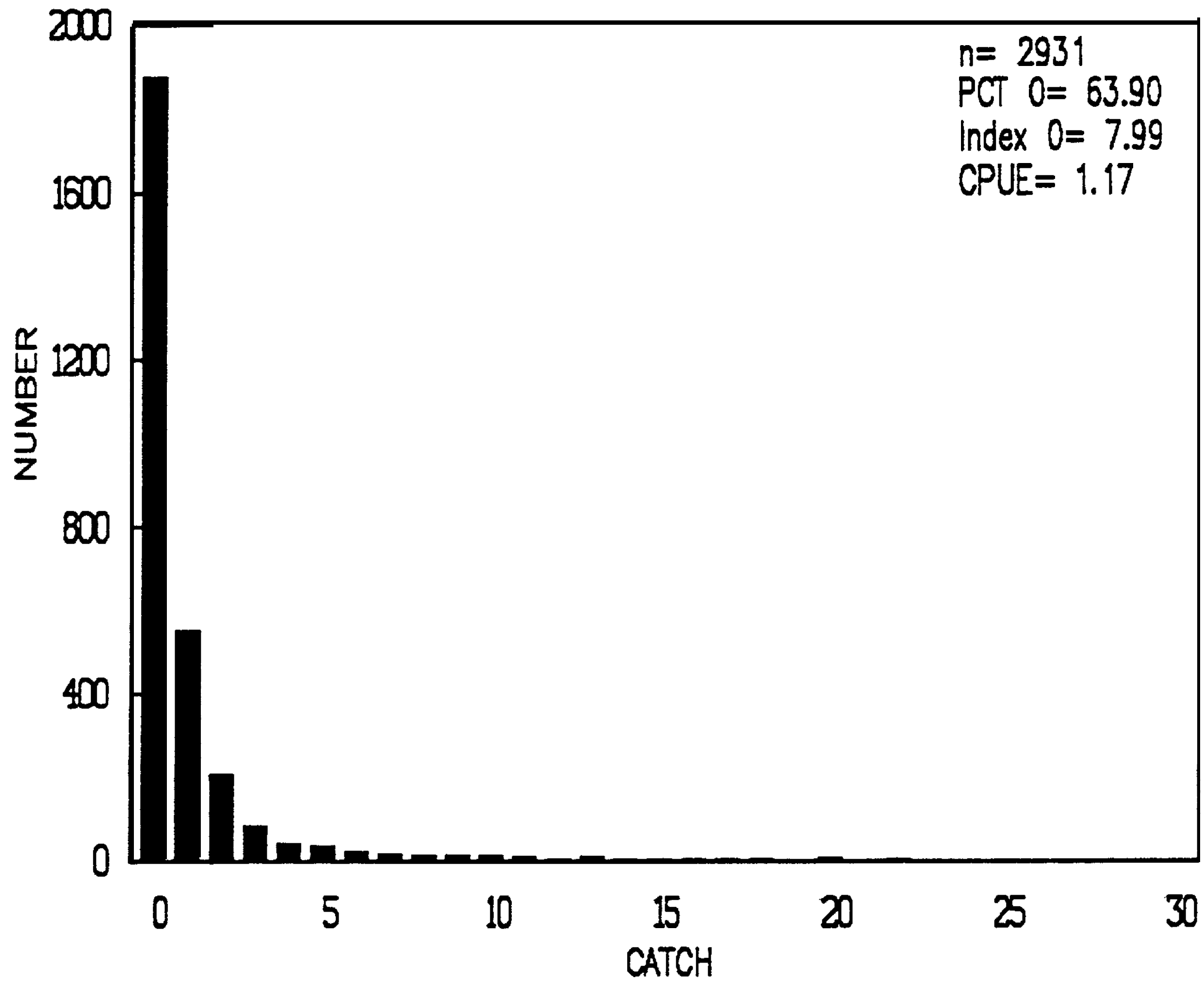


Figure A-5. Frequency distribution of boat electroshocker catches (raw data) in John Day Reservoir during 1984-1986.

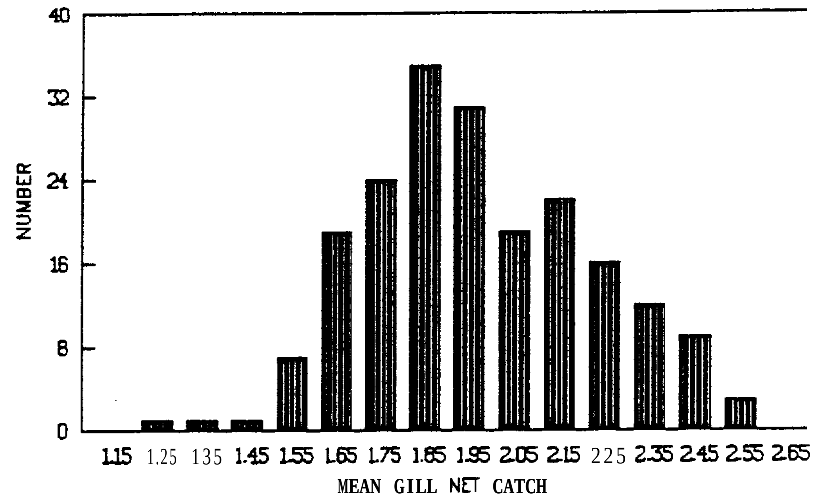


**Figure A-6. Frequency distribution of bottom-set gill net mean based on the proposed sampling design (3 areas, 2 times, 12 replicates) - fran 200 random samples of data from John Day Reservoir during 1984-1986.**

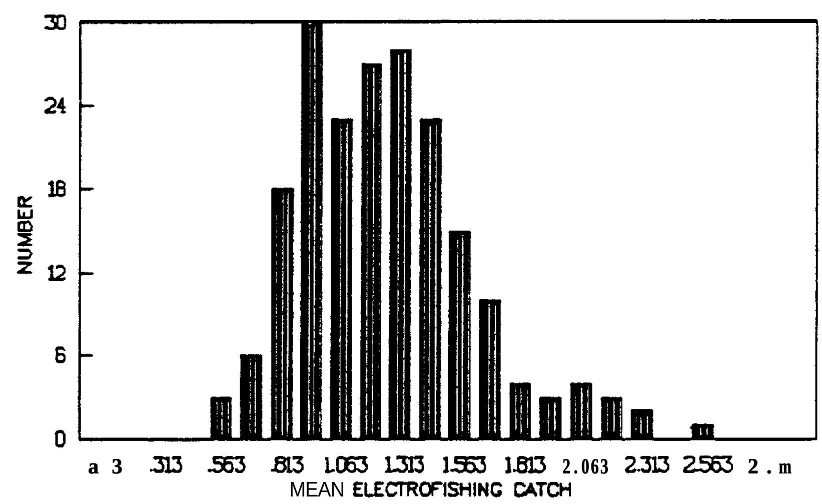


**Figure A-7. Frequency distribution of boat electroshocker mean based on the proposed sampling design (3 areas, 2 times, 12 replicates) - from 200 random samples of data from John Day Reservoir during 1984-1986.**

sample for gill net data was 1.97 with a variance of 0.07. The symmetry of the 200 random samples of the gill net CPUE data is indicated by the nearly equal values of the different measures of central tendency: median= 1.95, mode= 2.10, geometric mean= 1.96 (Table A-4). Likewise the electrofishing data had an arithmetic mean of 1.26, median of 1.23, mode of 1.12, and geometric mean of 1.21, with a relatively low variance (0.13). In contrast, the mode of the raw data sets was zero for both gill net and electrofishing samples. The raw data sets also have high measures of asymmetry in terms of standardized skewness (gill net= 68.59; electrofisher= 145.51) and standardized kurtosis (gill net= 208.75; electrofisher= 648.11).

Table A-4. Descriptive statistics for "raw" and "bootstrap" (mean of 200 samples, 12 replicates each, stratified by sampling design) data sets of catch per unit effort data for gill net and electrofishing samples collected in John Day Reservoir during 1984 -86.

| Statistic | Gill Net | | Electrofishing | |
|---|---|---|---|---|
| | Raw | Bootstrap | Raw | Bootstrap |
| sample Size | 2,325 | 200 | 2,931 | 200 |
| Mean | 1.645 | 1.972 | 1.168 | 1.259 |
| Median | 1.0 | 1.948 | 0 | 1.229 |
| Mode | 0 | 2.101 | 0 | 1.120 |
| Geom. Mean | -- | 1.955 | -- | 1.209 |
| Variance | 5.761 | 0.066 | 11.739 | 0.133 |
| Std. Dev. | 2.400 | 0.257 | 3.426 | 0.364 |
| Std. Error | 0.050 | 0.018 | 0.063 | 0.026 |
| Minimum | 0 | 1.242 | 0 | 0.581 |
| Maximum | 27 | 2.547 | 48 | 2.611 |
| Low. Quartile | 0 | 1.787 | 0 | 0.980 |
| Upp. Quartile | 2 | 2.146 | 1 | 1.463 |
| Skewness | 3.46 | 0.175 | 6.584 | 0.835 |
| Std. Skewness | 68.59 | 1.001 | 145.51 | 4.823 |
| Kurtosis | 21.09 | -0.378 | 58.65 | 0.964 |
| Std. Kurtosis | 208.75 | 1.092 | 648.11 | 2.784 |

The empirical "bootstrap" method was used to analyze the proposed sampling design; i.e., six cells (three reservoir areas . two time periods) and 12 replicates per cell. The Index-O (square root of relative frequency of zero catches, Bannerot and Austin (1983)) and the Ln(non-0) indices (natural logarithm of the non-zero catches) were much more efficient in estimating the parametric index values of the gill net data base compared to the mean CPUE estimator (Figure A-8). Both the

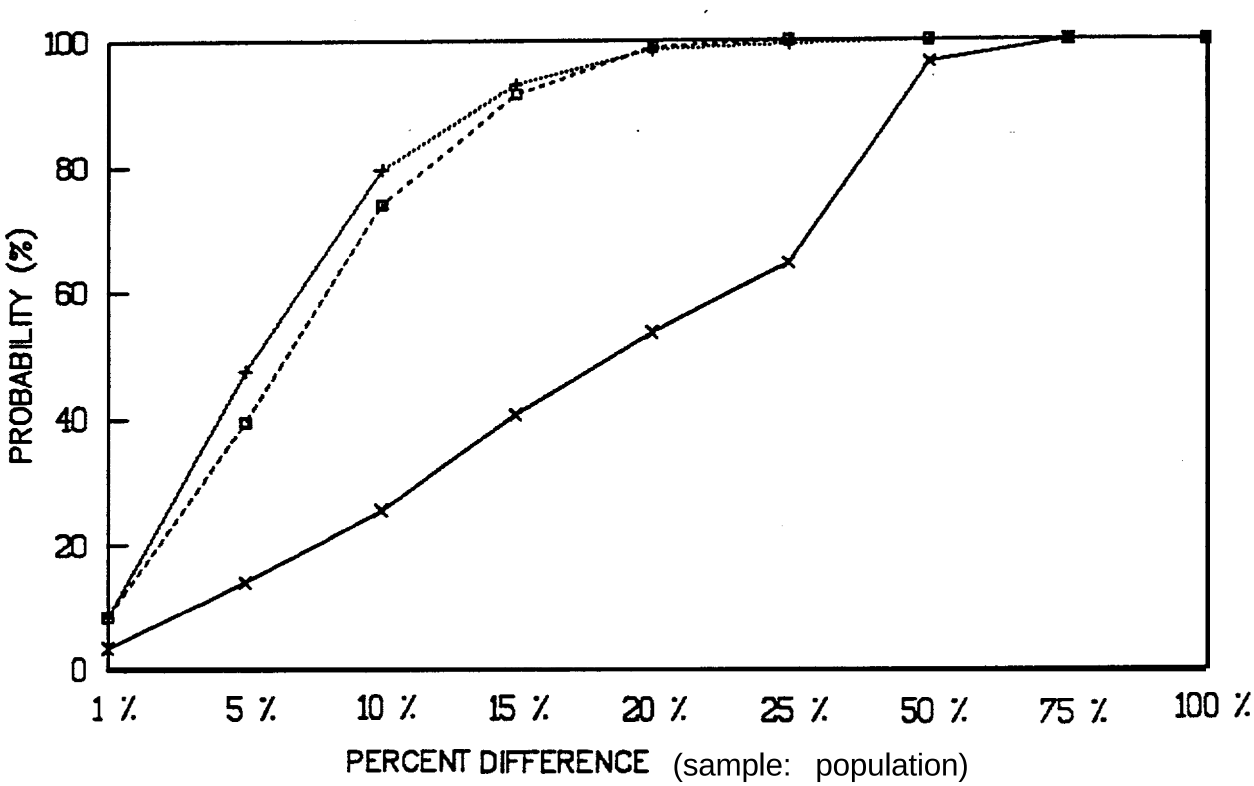


Figure A-8. Comparison of three CPUE indices for bottom set gill net samples; based on the proposed sampling design (3 areas, 2 times, 12 replicates) from 200 random samples of data from John Day Reservoir during 1984-1986. ( CPUE index methods: + = Index-0; ▮ = mean Ln(non-0) ; x= mean catch per unit effort )

Index-O and Ln(non-0) demonstrated over a 90% probability of estimating within ± 15% of the parametric index value ($\mu$). The mean CPUE index was much less sensitive; it could only estimate the parametric mean CPUE within ± 50% at probabilities greater than 90%. A similar analysis on electrofishing data showed that the Index-O, percent of zero catches, and Ln(non-0) were all accurate estimators of parametric index values (Figure A-9); i.e., each of these three indices are capable of accurately estimating the parametric index- value ($\mu$ ± 15%) 90% of the time. As in the gill net data, the mean electrofishing CPUE was less sensitive, but could still estimate $\mu$ ± 50% with a 90% probability.

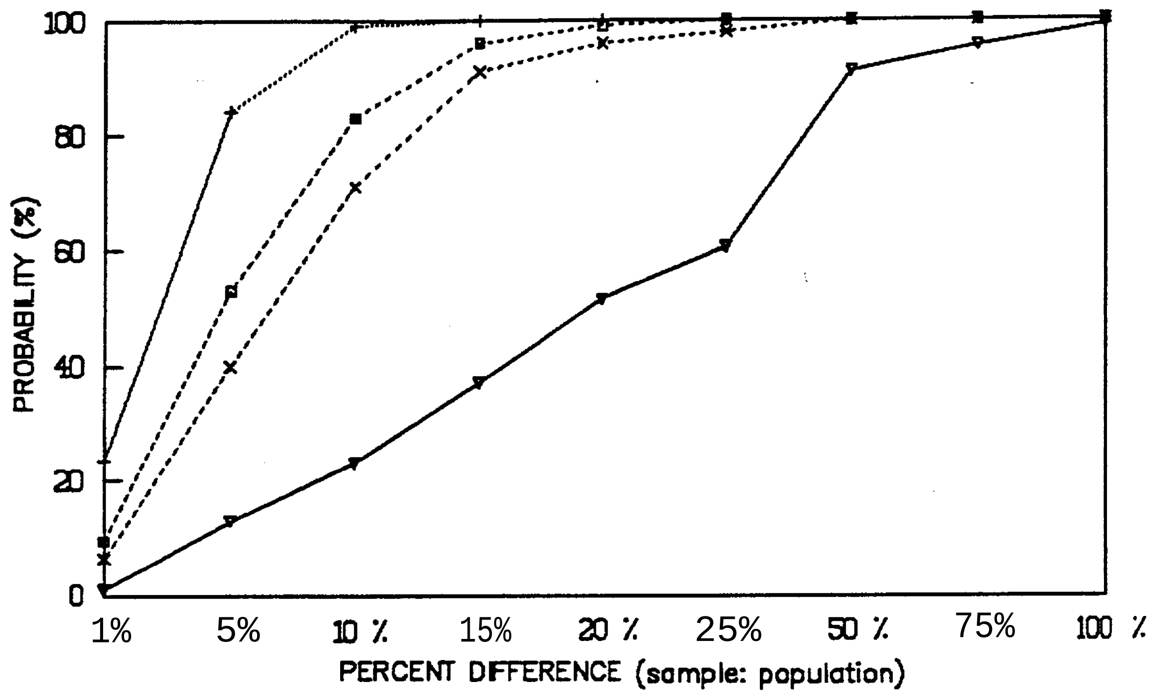


Figure A-9. Comparison of four CPUE indices for boat electroshocker samples; based on the proposed sampling design (3 areas, 2 times, 12 replicates) from 200 random samples of data from John Day Reservoir during 1984-1986. ( CPUE index methods: + = Index-0; ▮ = percent of zero catches; x= mean Ln(non-0); inverted A= mean catch per unit effort>

We also conducted "bootstrap" analysis to evaluate the statistical efficacy of varying sample size per replicate (2 to 24) of six CPUE indices for bottom set gill net samples based on the proposed spatio-temporal sampling design (3 areas, 2 times); this analysis was based on 200 random samples of the data base from John Day Reservoir during 1984-1986 (Appendix A-l). A similar sample size analysis was conducted for the electrofishing CPUE data base (Appendix A-2). The Index-O and mean Ln(non-0) indices approached an asymptotic-Type I error (P c 0.10) at an accuracy of $\mu$ ±10-20%. The effective sample size for Index-O to achieve 10% accuracy is 10-12 replicates per cell for both gill nets (Appendix Figure A-1.2) and boat electroshocker (Appendix Figure A-2.2). Maximum sampling efficiency for the mean of log of non-zero catches at 20%

accuracy was achieved for gill nets at 12 replicates per cell (Appendix Figure A-1.5), and at 14 replicates per cell for boat electrofishing (Appendix Figure A-2.5). Sampling efficiency for mean gill net CPUE asymptotes at 12 replicates per cell for a 50% accuracy (Appendix Figure A-1.3); accuracy of 20% or better cannot be achieved by mean CPUE (at $P < 0.50$), regardless of sample size. Likewise for electrofishing, 12 replicates per cell approached maximum sampling efficiency at 50% accuracy and $P < 0.50$ (Appendix Figure A-2.3).

## Fecundity-Size Relation

The average characteristics of female northern squawfish collected for gonad analysis were: a fork length of 399 mm, total weight of 901 g, ovary weight of 94 g, GSI of 9.8%, fecundity of 50,521 eggs, and egg diameter of 1.2 mm. The reproductive characteristics generally varied by size group (Table A-5). The observed range in fecundity was from 8,337 eggs in a fish 307 mm in length to 114,781 in a 483 mm fish. Fish weight was the best predictor of fecundity, and the relation was best described by a (nearly linear) power model (Table A-6). Considerable variation in fecundity occurred within a given fish size range; only 57% of the variation in fecundity was statistically accounted for by fish weight (Figure A-10). The within-fish replicate counts, however, were relatively precise; i.e., the replicate fecundity estimates had an average of 7.6% coefficient of variation (CV).

Table A-5. Mean values of biological characteristics of female northern squawfish used for gonad analysis stratified by fork length group.

| Fork Length Range (mm) | n | Fish Length (mm) | Fish Weight (g) | Ovary Weight (g) | GSI (%) | Fecundity (number) | Egg Diameter (mm) |
|---|---|---|---|---|---|---|---|
| 276-325 | 7 | 307.4 | 355.7 | 15.5 | 3.6 | 17,616 | 0.97 |
| 326-375 | 13 | 355.8 | 588.8 | 54.5 | 9.0 | 35,702 | 1.22 |
| 376-425 | 11 | 392.5 | 777.2 | 84.4 | 11.0 | 55,457 | 1.29 |
| 426-475 | 18 | 448.7 | 1261.7 | 149.3 | 11.7 | 66,688 | 1.24 |
| > 475 | 4 | 487.5 | 1456.5 | 124.3 | 10.1 | 66,059 | 1.15 |
| Mean: | | 398.5 | 901.4 | 93.6 | 9.8 | 50,521 | 1.20 |
| Sample Size: | | 53 | 52 | 54 | 52 | 54 | 54 |
| Standard Dev.: | | 56.6 | 382.3 | 61.5 | 4.3 | 25,984 | 0.23 |

Table A-6. Modeled relationships between various size and reproductive variables of a sample of female northern squawfish collected for gonad analysis from John Day Reservoir, 5 June to 7 July 1989.

| Criterion/ Predictor Variables | Model | Intercept | Slope | df | r | $R^2$ |
|---|---|---|---|---|---|---|
| Fish Weiaht: | | | | | | |
| Fish Length | | | | | | |
| | Linear | -1750.4 | 6.6214 | 51 | 0.958 | 0.918 |
| | Power | 0.00000386 | 3.20392 | 51 | 0.974 | 0.949 |
| Fecundity: | | | | | | |
| Fish Length | | | | | | |
| | Linear | -70438.7 | 304.479 | 52 | 0.661 | 0.437 |
| | Power | 0.0016 | 2.86933 | 52 | 0.704 | 0.496 |
| Fish Weight | | | | | | |
| | Linear | 7702.4 | 48.625 | 51 | 0.717 | 0.514 |
| | Power | 76.446 | 0.94949 | 51 | 0.753 | 0.567 |
| Fresh Gonad Weight | | | | | | |
| | Linear | 26575.9 | 257.238 | 52 | 0.608 | 0.370 |
| | Power | 5797.72 | 0.47701 | 52 | 0.742 | 0.550 |
| Gonadal Somatic Index: | | | | | | |
| Fish Length | | | | | | |
| | Linear | -4.42362 | 0.03560 | 51 | 0.455 | 0.209 |
| | Power | 0.000015 | 2.21127 | 51 | 0.544 | 0.296 |
| Fresh Gonad Weiaht: | | | | | | |
| Fish Weight | | | | | | |
| | Linear | -25.1729 | 0.13420 | 51 | 0.833 | 0.693 |
| | Power | 0.00071 | 1.71573 | 51 | 0.862 | 0.743 |
| preserved Gonad Weiaht: | | | | | | |
| Fresh Gonad Weight | | | | | | |
| | Linear | 12.8255 | 0.52639 | 52 | 0.851 | 0.725 |
| | Power | 0.9481 | 0.92225 | 52 | 0.939 | 0.881 |

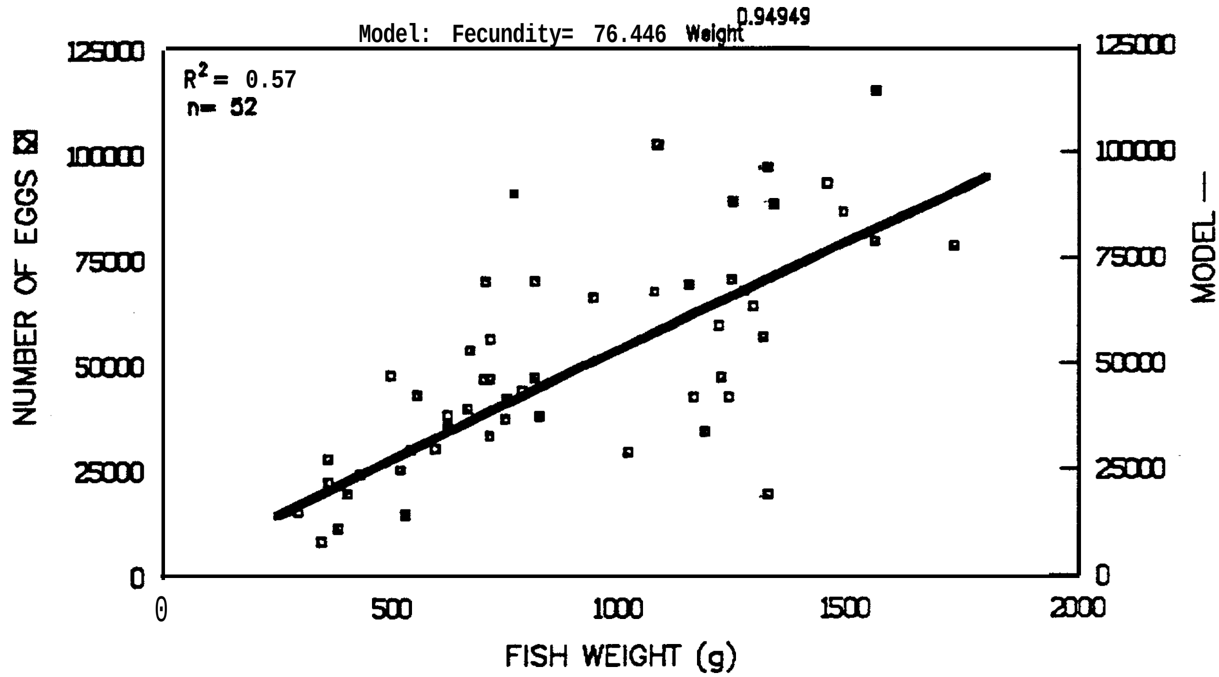


Figure A-10. Power model ($Y = aX^b$) of fecundity related to fish weight fran a sample of 52 female northern squawfish collected from John Day Reservoir, 5 June to 7 July 1989.

Ovary weight increased with fish weight over the entire size range. The percentage of ovary weight to somatic weight, however, increased from about 3.6% in 300 mm fish to 11% in 400 mm fish and then leveled off. No significant relation was observed between egg size and fish size, e.g., the linear relation between egg diameter and fish weight had a slope of 0.0001 and $R^2$ of 0.04. Mean egg diameter was relatively constant by fish size group, i.e., 0.97 mm for fish 276 to 325 mm'in length and about 1.23 mm for larger fish. Replicate egg diameter measurements within fish, however, were quite variable (mean CV= 24.5%). The frequency distribution of-individual measurements illustrates the wide range of egg sizes (0.25 to 2.15 mm), and a poly-modal distribution of egg diameters (Figure A-11).

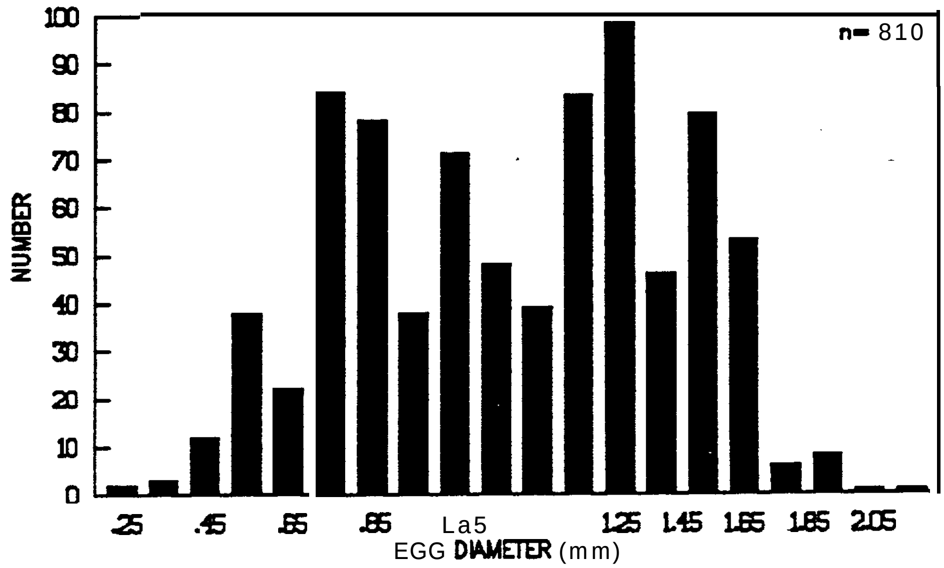


**Figure A-11. Frequency distribution of 810 egg diameter measurements (15 eggs per fish) from a sample of 54 female northern squawfish collected from John Day Reservoir, 5 June to 7 July 1989.**

## Year-class Strength Estimation Methodology

For all methods, estimated year-class strength correlated well with known initial population size when tested using the northern squawfish life history scenario and the random population structure at all levels of catch data; correlation coefficients ranged from 0.868 to 0.995 (Table A-7). There was no significant difference in correlation coefficients between methods at three years of catch data using the random theoretical population structure ($P < 0.05$). Using seven years of catch data, resulted in either the Extrapolation or the Rieman methods out-performing the El-Zarka method at correlation with the random theoretical population. Using 11 yrs of catch data and the random population structure, the Rieman method estimates correlated the best with the theoretical population. None of the methods appear to be robust when using the theoretical population structure having an increasing trend. At three years of catch data the Extrapolation give8 the best correlation of any method at any number of years of catch data (Table A-7). The methods also lack robustness when looking at the theoretical population structure with a decreasing trend at three years of catch data. At seven and 11 yrs of catch data the Extrapolation method correlates best at $r= 0.8968$ and $r= 0.9873$ respectively (Table A-7). The graphic representation of each index at each population

Table A-7. Correlation values of each year-class strength method compared to the theoretical population structures using the northern squawfish and walleye life history scenarios.

| Fish Species: Years of Catch | Method* | Population Structures: Random | Increasing Trend | Decreasing Trend |
|---|---|---|---|---|
| **Northern Scmawfish:** | | | | |
| 3 | 1 | 0.9003 | 0.5769 | -0.1633 |
| | 2 | 0.9824 | 0.7942 | -0.7274 |
| | 3 | 0.8789 | 0.0874 | 0.0149 |
| 7 | 1 | 0.9035 | 0.5331 | 0.0549 |
| | 2 | 0.9829 | -0.2282 | 0.8968 |
| | 3 | 0.9924 | 0.3215 | 0.0601 |
| 11 | 1 | 0.9021 | 0.4859 | 0.3448 |
| | 2 | 0.8681 | -0.8421 | 0.9873 |
| | 3 | 0.9954 | 0.4188 | 0.1641 |
| **Walleves:** | | | | |
| 3 | 1 | 0.8396 | 0.4338 | 0.0590 |
| | 2 | 0.9855 | -0.9994 | 0.9835 |
| | 3 | 0.9891 | 0.0250 | 0.6408 |
| 7 | 1 | 0.7320 | 0.3814 | 0.1757 |
| | 2 | 0.7091 | -0.9840 | 0.9689 |
| | 3 | 0.8035 | 0.2998 | 0.2151 |
| 11 | 1 | 0.8465 | 0.3869 | -0.9385 |
| | 2 | 0.5144 | -0.9471 | 0.9697 |
| | 3 | 0.9812 | 0.6242 | -0.7637 |

* 1 = El-Zarka
2 = Extrapolation
3 = Rieman

scenario and at each number of years catch data are presented in Appendix A-3.

Using the walleye life history scenario with the random population structure at three years of catch data, the Extrapolation and Rieman methods correlated better than the El-Zkka method r= 0.9855 and 0.9891 respectively (Table A-7). There was no significant difference in correlation coefficients between the methods at seven years of catch data (P < 0.05). At 11 years of data the Rieman method proved to be the best at correlating with the random theoretical population structure (r= 0.9812). When testing the methods with an increasing trend in population size none of the methods correlated well, with the Rieman method the best at 11 years of catch data (r= 0.6242). When the methods were tested using a decreasing trend in population sizes the Extrapolation method correlated best at all levels of catch data.

## Age Determination Precision

The final age determinations of northern squawfish using scale samples had a range of 4 to 14 years (Figure A-12). We found no

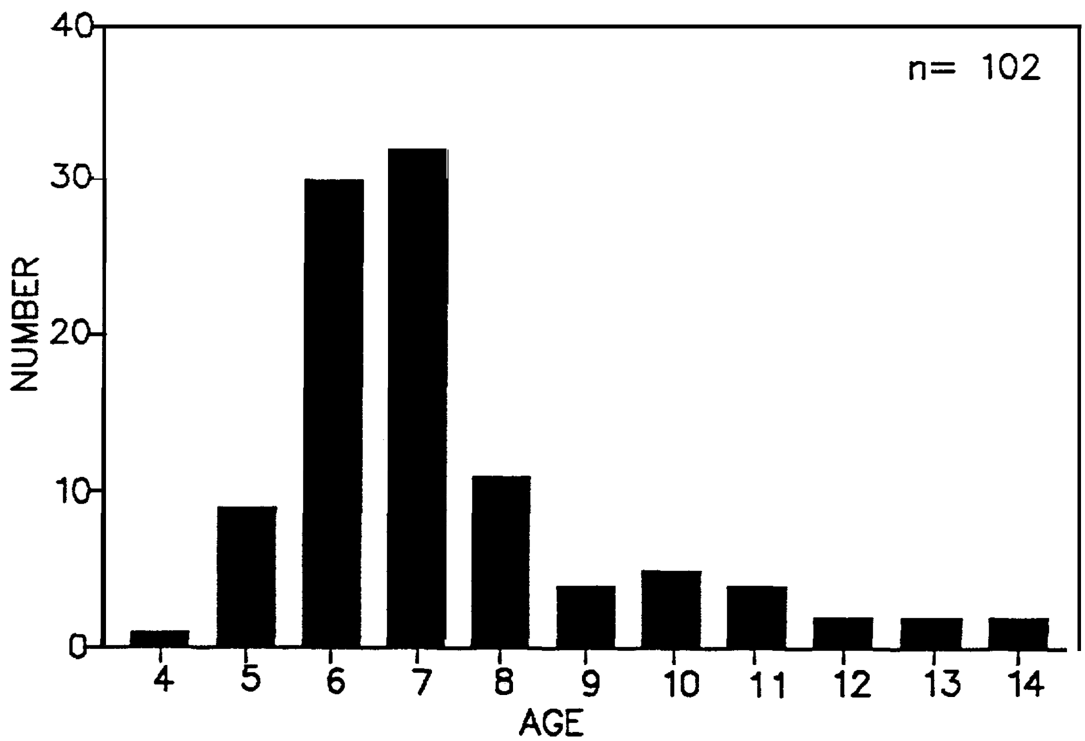


Figure A-12. Age structure of northern squawfish caught in bottom gilt nets from final age determinations.

significant difference (t= 0.796, P= 0.05) between the means of the preliminary aging of northern sguawfish caught with bottom gill nets (mean= 7.6) compared to the final aging (mean= 7.3).

The precision estimates of aging northern sguawfish (n= 153) caught in bottom gill nets and by angling from McNary Dam tailrace were APE= 7.38% and CV= 0.0992 (Appendix A-4).

## DISCUSSION

### Predator Abundance Index

This analysis was conducted to answer the question: *Given the proposed sampling design,* is *the CPUE Predator Abundance Index feasible?* The criteria we used for judging feasibility was if the index can detect a low enough percent difference from the parametric CPUE measure at a high enough probability level to be used as a management tool. Prior to conducting this sample size analysis, we assumed that a CPUE-based Predator Abundance Index could only detect "order of magnitude" differences; the regional consensus was that a Predator Abundance Index had to have at least order of magnitude accuracy to be of use to management. We have now estimated the accuracy and the associated probability of attaining that accuracy for various CPUE indices, based on a large data base of northern squawfish CPUE collected with two sampling methods in John Day Reservoir during 1984-86. We have concluded that various CPUE indices have high probabilities (> 90%) of estimating parametric means within 50%; i.e., they are better than "order of magnitude" estimators. Therefore, CPUE measures are technically feasible methods to assess relative abundance of northern sguawfish in Columbia River reservoirs. Thus, fishery managers now have more information to evaluate the utility of the Predator Abundance Index.

The relations between the accuracy of the index (percent difference between the sample CPUE estimate and the parametric CPUE value) versus the empirical probability of achieving that accuracy (number of times out of 100 "bootstrap" trials) provide standardized criteria to judge the effectiveness of various Predator Abundance Index methods, e.g., Figures A-8 and A-9. The point on the x-axis where the curve approaches an asymptote represents the sensitivity of the CPUE estimator; and the corresponding value of the y-axis represents the probability that a given accuracy can be achieved, i.e., a measure of the uncertainty of the estimator. The accuracy-probability relations can be used in two ways: (1) by setting the minimum accuracy that is required (e.g., ±20% $\mu$), one can see for a given sampling method and CPUE estimator what the probability of achieving that accuracy is; or (2) by setting the degree of uncertainty that is acceptable (e.g., 80% probability of achieving a given percent difference= a 20% Type I error) -- one can see the maximum accuracy that is attainable. The curves relating sample size to probability for various accuracy levels (Appendices A-l and A-2) provided a way to evaluate the efficacy of the proposed sampling design in terms of required replicates per cell; asymptotes of these curves represent the point of diminishing returns, i.e., where additional investment in sampling effort does not result in a reduction of uncertainty.

Based on the "bootstrap" analysis, we selected the Index-O (Bannerot and Austin 1983) and the mean of the log of non-zero catches as the most sensitive indices of CPUE data (Figure A-13). From the

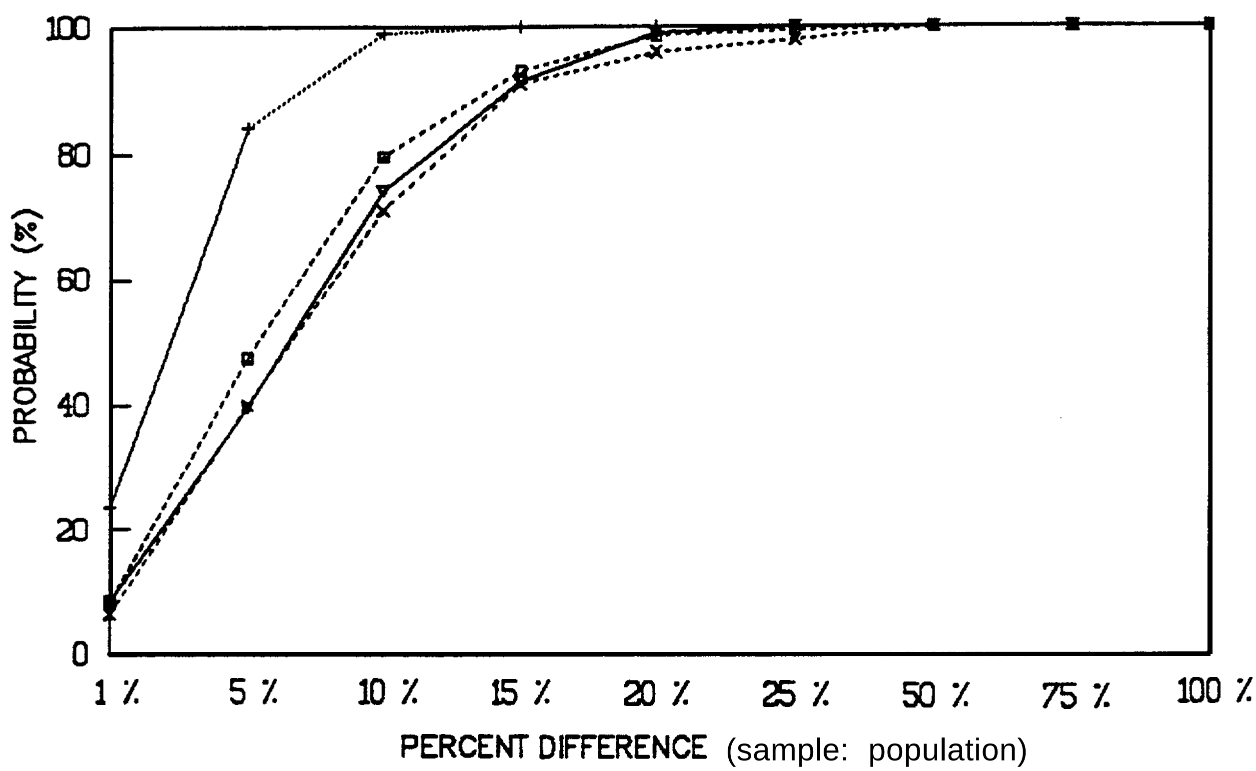


Figure A-13. Comparison of two selected indices (Index-O, and mean LN(non-zero)) by sampling gear type. ( CPUE index methods by gear (ES= boat electroshocker and GN= bottom gill net): + = ES Index-0; ▮ = GN Index-0; inverted A= ES Ln(non-0); x= GN Ln(non-0) )

results of the sample size analyses (Appendices A-l- and A-2), we concluded that 12 replicates per cell were needed for the most efficient indices {i.e., Index-O and Ln(non-O)} to have high probabilities (P < 0.20) of achieving high accuracy (difference from u ≤ 20%). The standard mean CPUE is also a useful index if a high degree of accuracy is not required; given 12 replicates per cell, mean CPUE achieved 50% accuracy at P < 0.10.

## Fecundity-size Relation

The mean fecundity of northern squawfish from John Day Reservoir was 50,521 eggs per female, ranging from 8,337 to 114,781 eggs. This estimate is somewhat higher than the fecundity range reported for northern sguawfish from Lake Washington, Washington -- 6,037 to 95,089 eggs (Olney 1975) and from St. Joe River, Idaho -- 2,700 to 75,000 eggs (Reid 1971). Fecundity of our sample of northern sguawfish varied nearly linearly with fish weight, however, the variability was high for a given size group. • Olney (1975) also observed a linear relation in which fish weight accounted for about 77% of the variation in fecundity. Factors such as egg development and thermal history may affect the fecundity-size relationship. We propose that future studies use a multiple log-linear regression model to test the factors affecting northern sguawfish fecundity (F) and reproductive potential:

$$\log F = \log a + b \log (X1) + c \log (X2) + d \log (X3), \quad (10)$$

where, Xi are independent variables such as fish weight, percent of egg diameters over a threshold (ripe) size, and cumulative thermal units.

Mean ovary weight as a percentage of body weight (GSI) was 9.8%, with a standard deviation of 4.3% for our 1989 sample. Vigg (unpublished data) determined a mean GSI of about 7% for female northern squawfish in John Day Reservoir during 1983 and 1986. In Lake Washington, the mean GSI for females was 9.9% (Olney 1975); and in the St. Joe River GSI for females ranged from 5 to 16% (Beamesderfer 1983).

The mean diameter of eggs in ripe ovaries of northern sguawfish was 1.20 mm; there was no apparent relation between fish size and egg size. Substantial variation was observed within individual ovaries; overall egg diameters had a poly-modal frequency distribution, ranging from 0.25 to 2.15 mm diameter. This variability in egg diameter suggests that northern sguawfish ovaries contain eggs in various stages of development just prior to spawning. The stages of ova development in northern sguawfish in terms of egg viability and reproductive potential has not been studied.

## Year-class Strength Estimation Methodology

Year-class strength analyses have been used as a relative measure to predict how population have responded to changes in biotic and abiotic factors (Ritchie and Colby 1988; Koonce et *al.* 1977; Stevens 1977; Forney 1971). Specifically, one application of year-class strength analyses has been to indirectly assess factors that affect the recruitment of fish to a population relative to other recruitment years (Chevalier 1977). In large riverine-reservoir systems, actual population estimates of age-group zero fish are usually not possible --

therefore some index must be used to indicate the relative size of year-classes. Catch per unit effort (CPUE) indices of relative abundance are feasible to measure, and by collecting additional data, for example scales or otoliths, age specific (CPUE) relations can be achieved.

The objectives of this analysis were to review the current methods employed to determine relative year-class strengths using catch data generally collected (i.e., catch per unit effort and age composition) during a fishery and to compare these methods using correlation analyses. The end product being recommendations as to which method would be best suited for year-class strengths analysis under a given set of conditions. We used the terms, *theoretical population* to be the known year class values we assigned each year, age *group* to be the fish of the same calendar year represented in the catch data, and *year-class* to be the fish spawned or hatched in a given year (Ricker 1975).

No single method was best at correlating with all combinations of theoretical population structures and numbers of years of catch data. The northern squawfish life-history scenario indicates that if year-class strength varies in a random fashion through time, then any of the methods tested would be adequate given three years of catch data. With additional years of catch data, both the Rieman or Extrapolation methods yield better estimates of relative year-class strengths given the assumption of this analysis.

The results from the walleye life-history scenario (having less age groups in the population than the northern sguawfish scenario) show that the Extrapolation or Rieman methods should be used if only three years of catch data are available; with the addition of more years of catch data, the Rieman method would be best. When we examine the results of the methods in terms of their ability to predict relative year-class strengths with theoretical population structures that have definite trends, we observed that the methods respond erratically and that the best method to use is not readily apparent.

El-Zarka (1959) patterned his analysis of year-class strengths after Hile (1941). The rational for Rile to use successive accumulation of the percent difference makes sense biologically because each years growth is an addition to the sum of the previous years of growth. This rational does not hold true for the El-Zarka method however, since a given year-class strength does not include a summation of previous year-class strength. This discrepancy of logic could account for the overall low correlation values seen using the El-Zarka method to predict relative year-class strengths. The Extrapolation method, proved, to be a good method to use given the assumption that the population to be tested has random fluctuations in year-class strength. Care should be taken when using this method due to the fact that the smaller fish just after recruitment have a somewhat higher natural mortality than the stock as a whole, however, if the age specific mortality rates are the same this should be minimized. Caution should also be used when extrapolating back from the observed catches to the y-intercept, especially if the fish are not recruited to the gear for several years. This could possibly underestimate the absolute number of recruits; the relative year-class numbers however, should be unaffected. The Rieman method also correlated well in those cases where year-class strengths varied in a random fashion and would be the best overall choice provided the assumptions that age specific mortality and catchability are constant through time are met. Thus, any deviation of the data from the mortality line is due to fluctuations in year-class strength.

The results from the analysis show that all variables tested affect the ability of all the methods to predict relative year-class strengths to some extent and that these factors need to be taken into account when choosing the correct method. for analysis. Future analysis that would test additional variables, such as those listed in Table A-2, with these methods could give us explanations for the unexplained shortcomings of the methods, and by adding stocasticity to the variables, we could approximate the variability seen in nature.

## Age Determination Precision

After completion of aging the northern squawfish collected in the bottom gill nets, we found that the final scale aging by the same reader (C.C. Burley) was not significantly different from that of the preliminary aging reported by Vigg and Burley (1989). Six of the scale samples were excluded from the final age analysis, however, due to irregularities in those scales.

For determining the precision of scale aging by our reader (C.C. Burley) we added northern squawfish scale samples collected from the McNary Dam tailrace boat restricted zone. These fish were significantly larger and older than those fish collected by bottom gill nets in the main reservoir (Vigg and Burley 1989). This allowed us to test the precision of aging fish scales using a larger sample size with the older fish better represented.

A common technique for assessing the precision of fish age determinations from scale samples is to compare the percent agreement of age determination by several readers, as discussed by Beamish and Fournier (1981), and Chang (1982). This method does not evaluate the degree of precision equally for all fish species. For example an agreement of 95% ±1 yr for a species that is represented by only a few young year-classes would be relatively poor compared to 95% agreement ±1 yr for a fish with many older year-classes represented in the fishery. Beamish and Fournier (1981) use the average percent error as an index of precision, however, as Chang (1982) points out, this index assumes that the range of fish year-classes available to the fishery increases in proportion to the average age of fish in the fishery. A better index of the reproducibility of age determinations is to use the coefficient of variation because variance is a better estimator than absolute difference as it is an unbiased and consistent estimator.

The precision estimates of our reader aging northern squawfish was better than 90 percent. The error in aging fish scales should be considered when applying these results to population statistics. The key to precision in estimates of fish age relies on the ability to consistently apply the established criteria for assigning an annulus.

In order to meet this goal, trained personnel using common methods and terminology must be applied.

## Summary and Conclusions

(1) The predator abundance index was determined to be feasible in terms of sample size required to detect significant differences in various measures of catch per unit effort (CPUE), given the spatio-temporal sampling design stratified by three reservoir areas (forebay, mid-reservoir, and tailrace) and two time periods (early and late season). The Index-O and Ln(non-0) were the most accurate indices of CPUE. Several facts lead us to these conclusions:

(a) Overall gill net catches have a skewed (negative binomial) distribution with 38.6% zero catches and a mean of 1.65 catch per hour.

(b) Overall electroshocker net catches have a more skewed (negative binomial) distribution with 63.9% zero catches and a mean of 1.17 catch per transect.

(c) Means of the 200 random samples of the 1984-86 John Day Reservoir data base for both gill net and electrofisher samples had relatively normal frequency distributions.

(d) Untransformed CPUE (mean-all) detected better than order of magnitude differences in index values at high probabilities, but was the least sensitive index. Given 12 replicates per cell, mean CPUE could detect a 50% difference (P= 0.03) for gill net samples, and could detect a 75% difference (P= 0.03) for the electroshocker samples.

(e) By dividing the catches into two components (1) zero catches and (2) non-zero catches -- two sensitive CPUE indices could be derived. The index-0 and LN(non-zero) were the most sensitive indices for both gill nets and electroshocker.

(f) Given the proposed sampling design and the two proposed CPUE indices, the Predator Abundance Index is feasible for detecting 10 to 20% differences. For gill net samples, the Index-O could detect a 10% difference (P= O.2O), and the LN(non-zero) index could detect a 10% difference (P= 0.26). For electroshocker samples, the Index-O could detect a 10% difference (P= 0), and the LN(non-zero) index could detect a 10% difference (P= 0.25).

(g) Based on the asymptotes of the probability-sample size curves, 12 replicates per cell appears to be near the optimum sample size for the proposed sampling design for both gill net and electrofishing samples.

(2) The analysis of 54 female northern sguawfish gonads in pre-spawning condition demonstrated considerable unexplained variability in the fecundity-size relation and within-fish egg size.

(a) Mean fecundity was 50,521 eggs per female, with a standard deviation of 25,984 eggs. Fecundity varied nearly linearly with fish weight, and ranged from 8,337 to 114,781 eggs. Factors such as egg development and thermal history may affect the fecundity-size relationship and the reproductive potential of the population.

(b) Mean ovary weight as a percentage of body weight (GSI) was 9.8%, with a standard deviation of 4.3%.

(c) Mean egg diameter was 1.20 mm, with a standard deviation of 0.23 mm. Egg diameters had a poly-modal frequency distribution showing several stages of egg development occurring within the ovary prior to spawning.

(3) Of the methods tested to estimate relative year-class strengths, the results of the Rieman method had the highest correlations with the theoretical population for both the northern squawfish and walleye life history scenarios when using the random population structure.

(a) The Rieman Method estimates had correlations with the known northern sguawfish theoretical random population structure of $r=$ 0.89, 0.99, and 0.99 for data time series of 3, 7, and 11 years, respectively; for the walleye life history scenario, the respective correlations were $r=$ 0.99, 0.80, and 0.98.

(b) The three methods varied greatly in their ability to predict relative year-class strengths when tested using theoretical population structures having either increasing or decreasing trends.

(4) Aging northern sguawfish using scales as the aging structure was found to have an average percent error of 7.38% and a coefficient of variation of 0.0992.

(a) The final age determination of the fish sampled in the John Day Reservoir showed a range of 4 to 14 years.

(b) We found no significant difference ($P=$ 0.05) between the mean age determination of northern squawfish, caught in bottom gill nets, during the preliminary aging (7.6 years) reported in Vigg and Burley (1989) with the final mean age determination (7.3 years) reported here.

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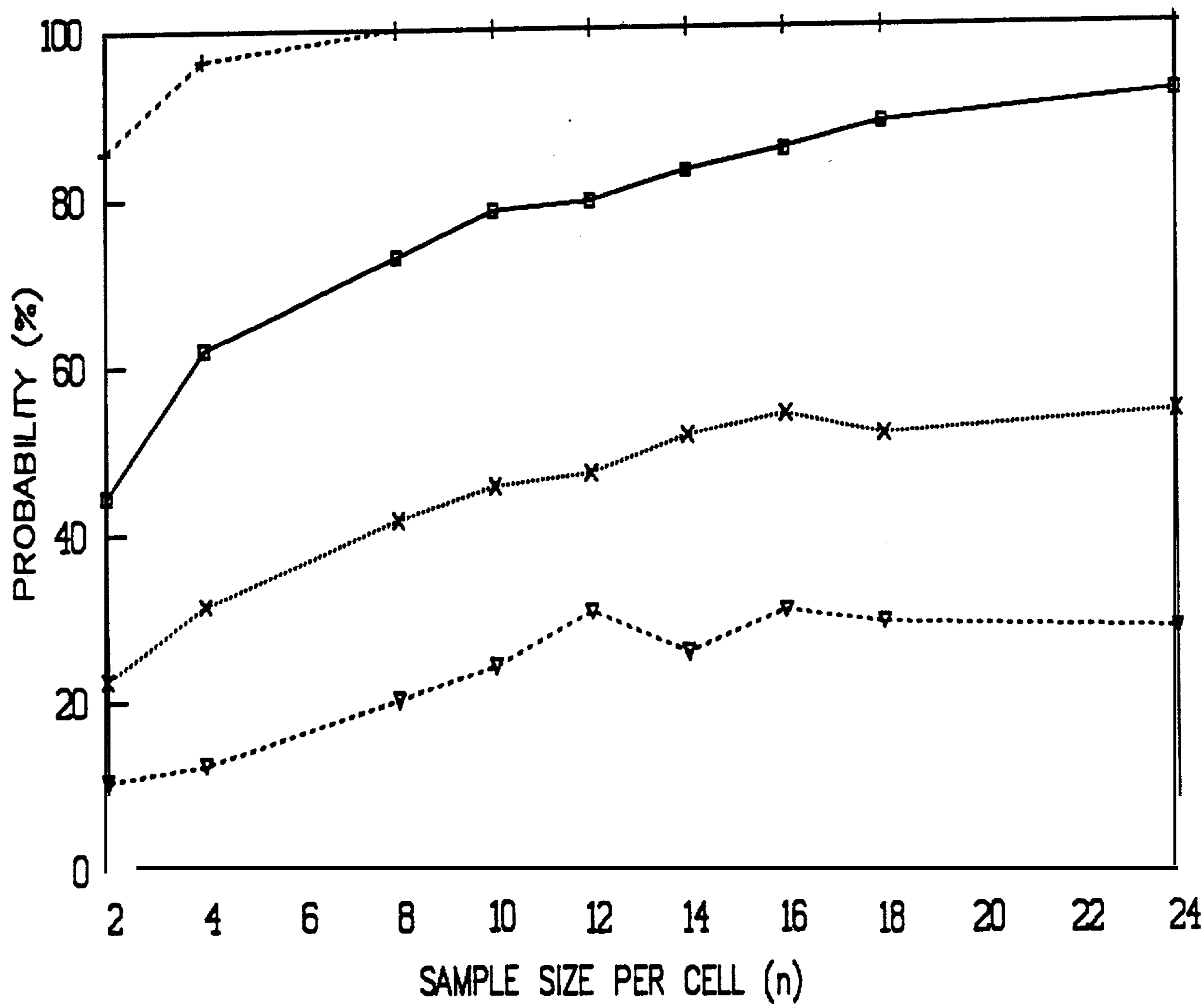
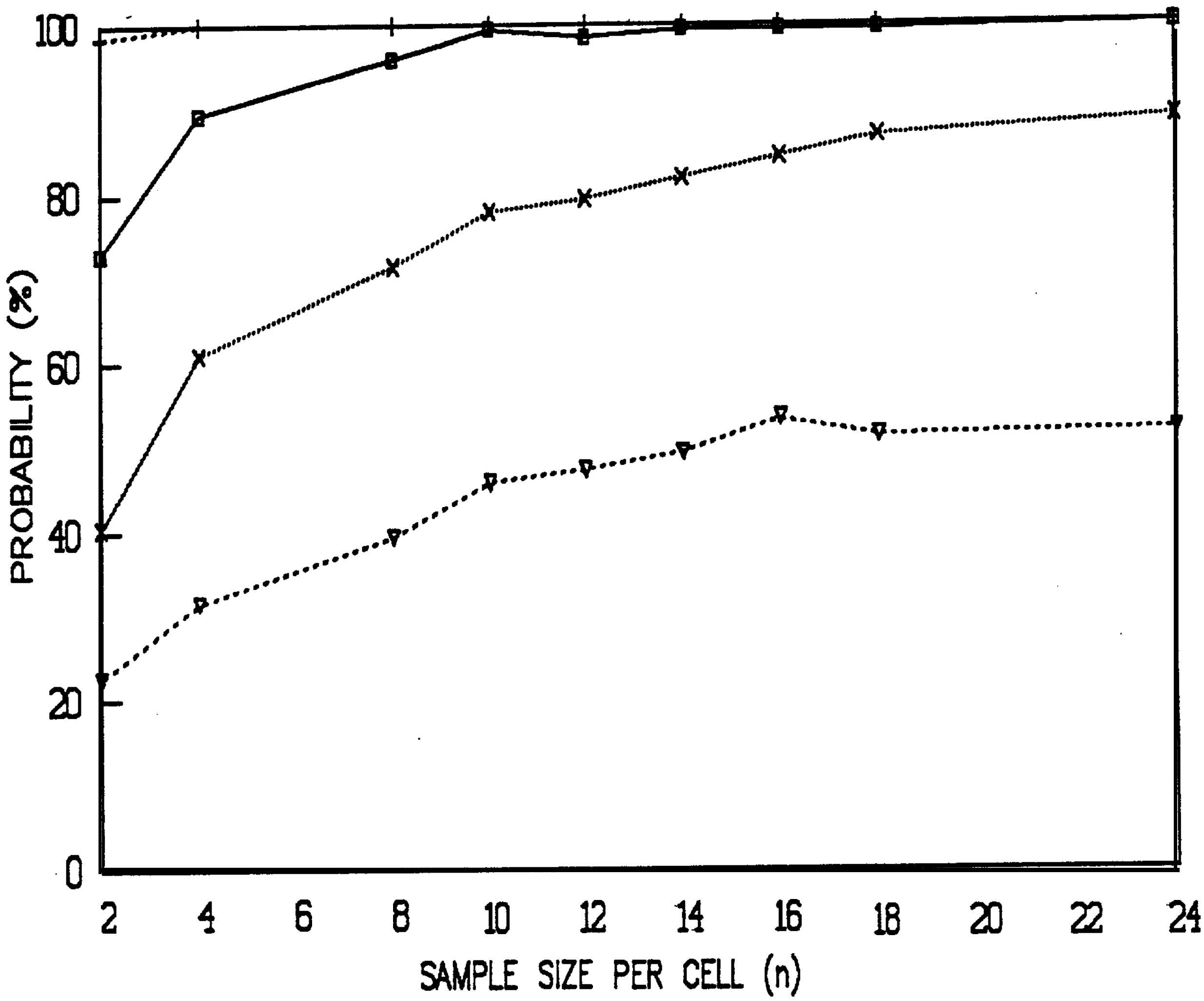
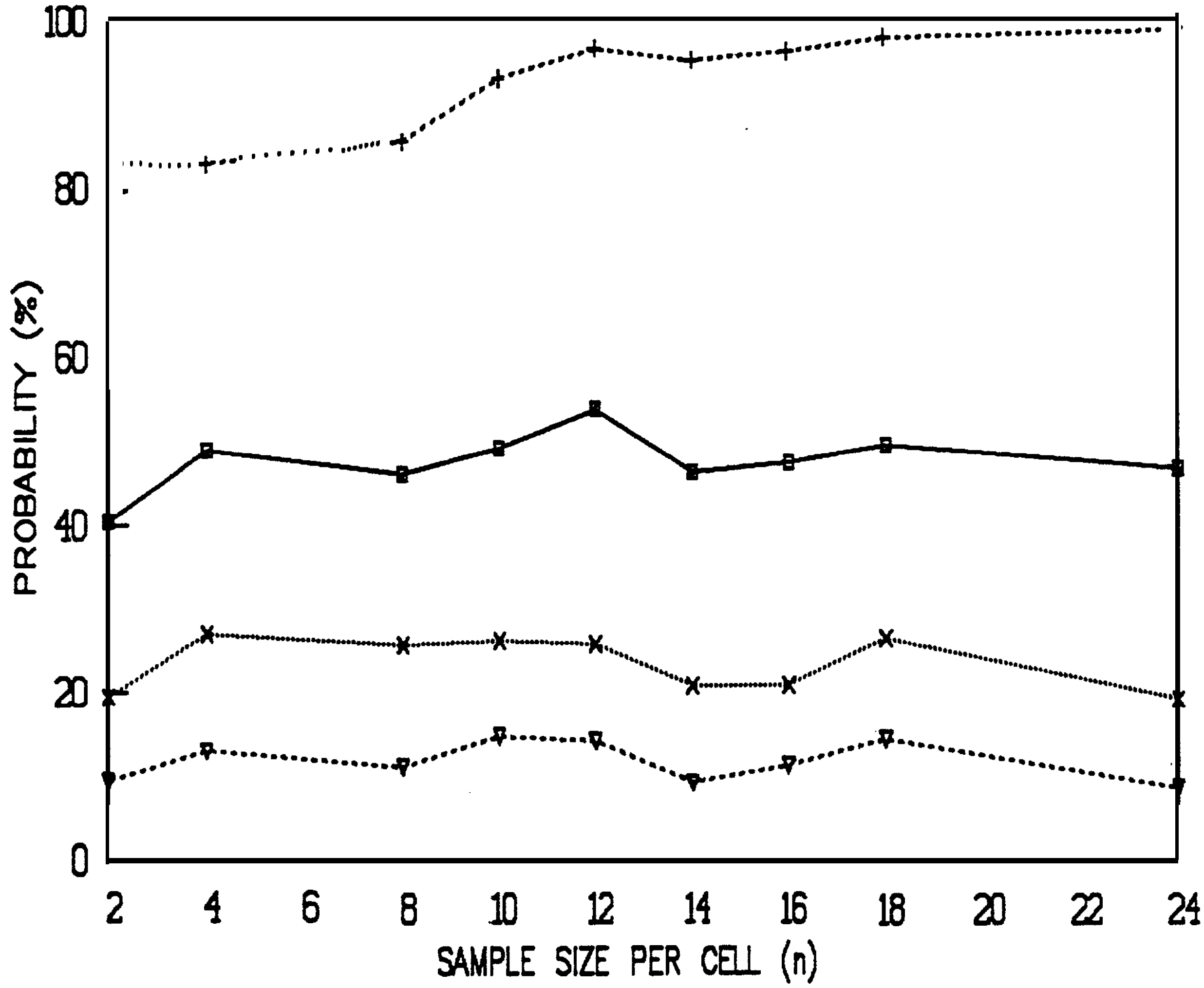
Appendix A-l. Bootstrap analysis of six CPUE indices for bottom set gill net samples based on the proposed spatio-temporal sampling design (3 areas, 2 times); and comparing the statistical efficacy of varying sample size per replicate (2 to 24) -- from 200 random samples of data from John Day Reservoir during 1984-1986.



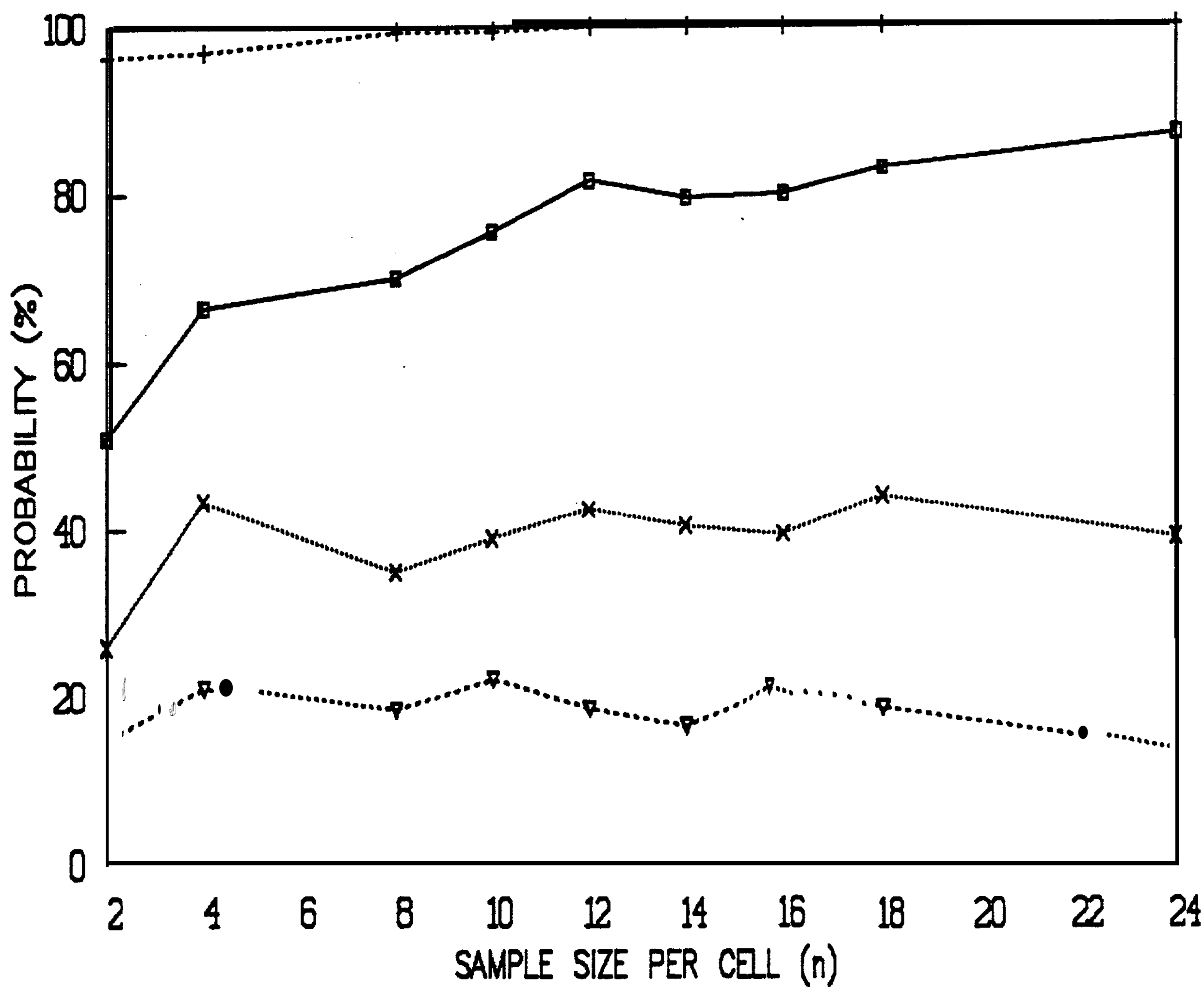

Appendix Figure A-l.1 Bottom gill net samples -- percent zero catches. ( Percent difference population-sample (PD): + = PD ≤ 50%; ▮ = PD ≤20%; x= PD ≤ 10% ; inverted ▲= PD ≤ 5% )



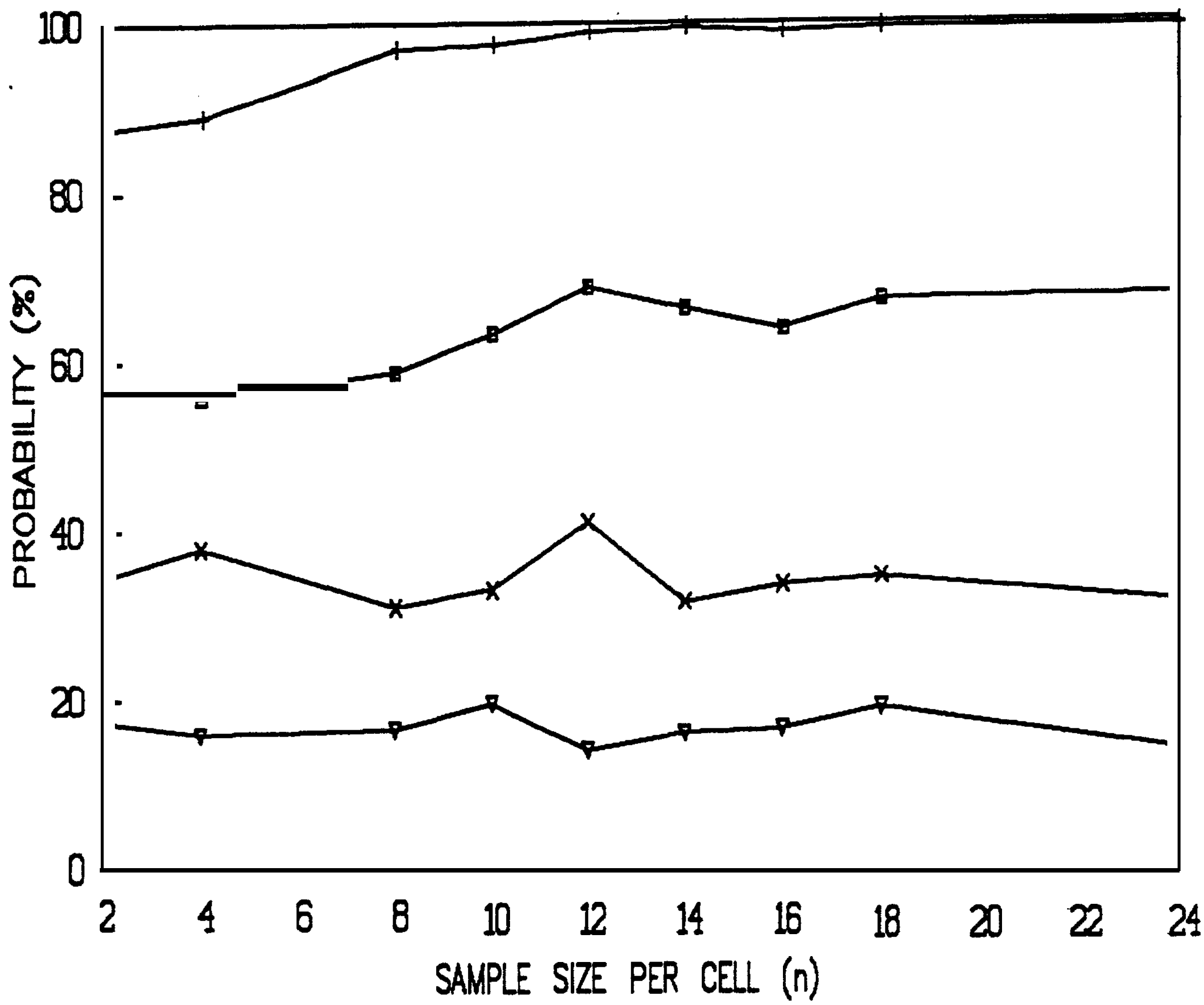

Appendix Figure A-1.2 Bottan gill net samples -- square root (percent zero catches). ( Percent difference population-sample (PD): + = PD ≤ 50%; ▮ = PD ≤20%; x= PD ≤ 10% ; inverted ▲= PD ≤ 5% )



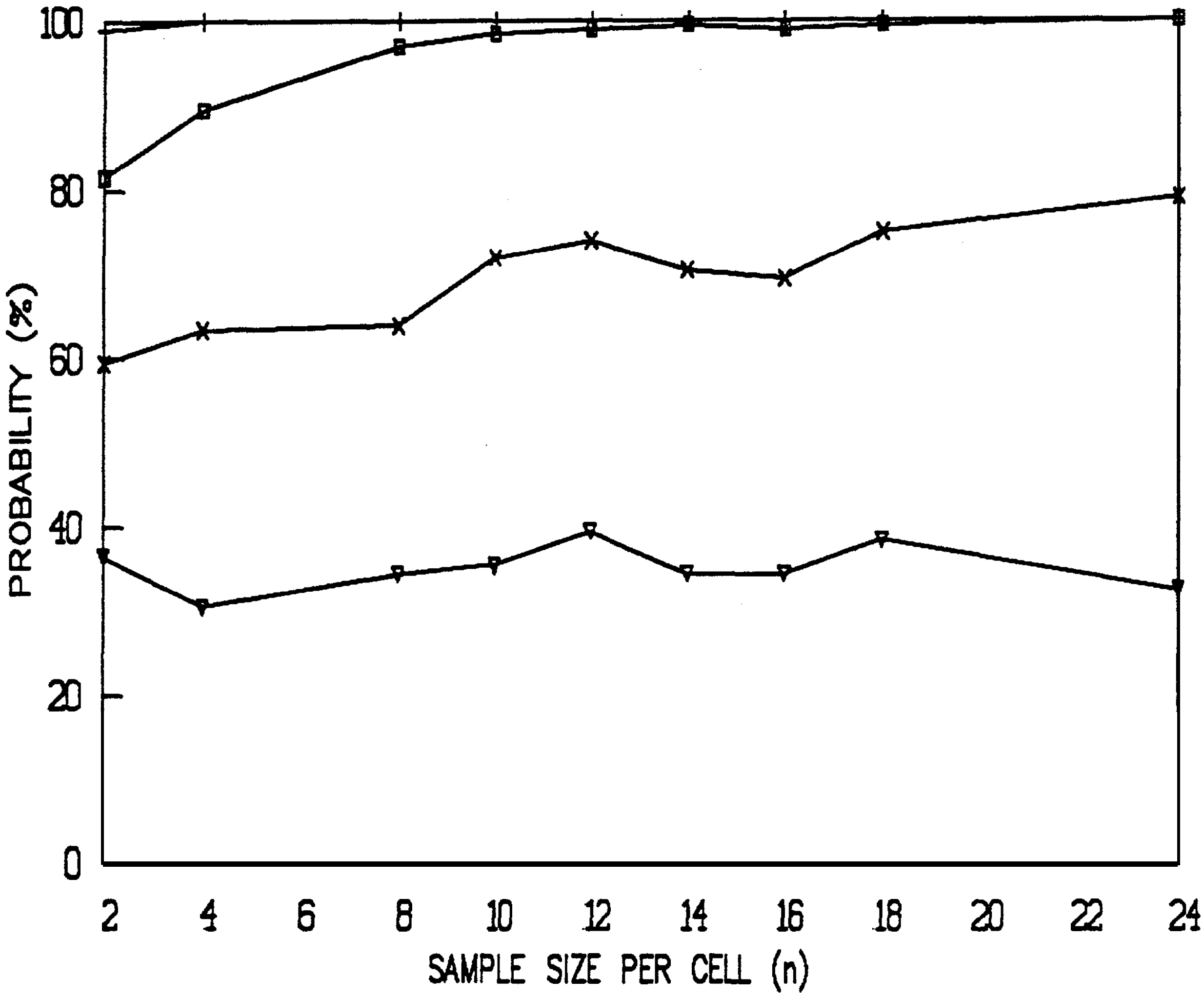

**Appendix** Figure A-1.3 Bottom gill net **samples** -- mean of all catches. ( Percent difference **population-sample (PD)**: + = PD ≤ 50%; ▮ = m ≤20%; x= m 4 10% ; inverted A= PD ≤ 5% )




Appendix Figure A-1.4 Bottom gill net samples -- mean LN(all catches). ( Percent difference population-sample (PD): + = PD ≤ 50%; ▮ = PD ≤20%; x= PD ≤ 10% ; inverted A= PD ≤ 5% )

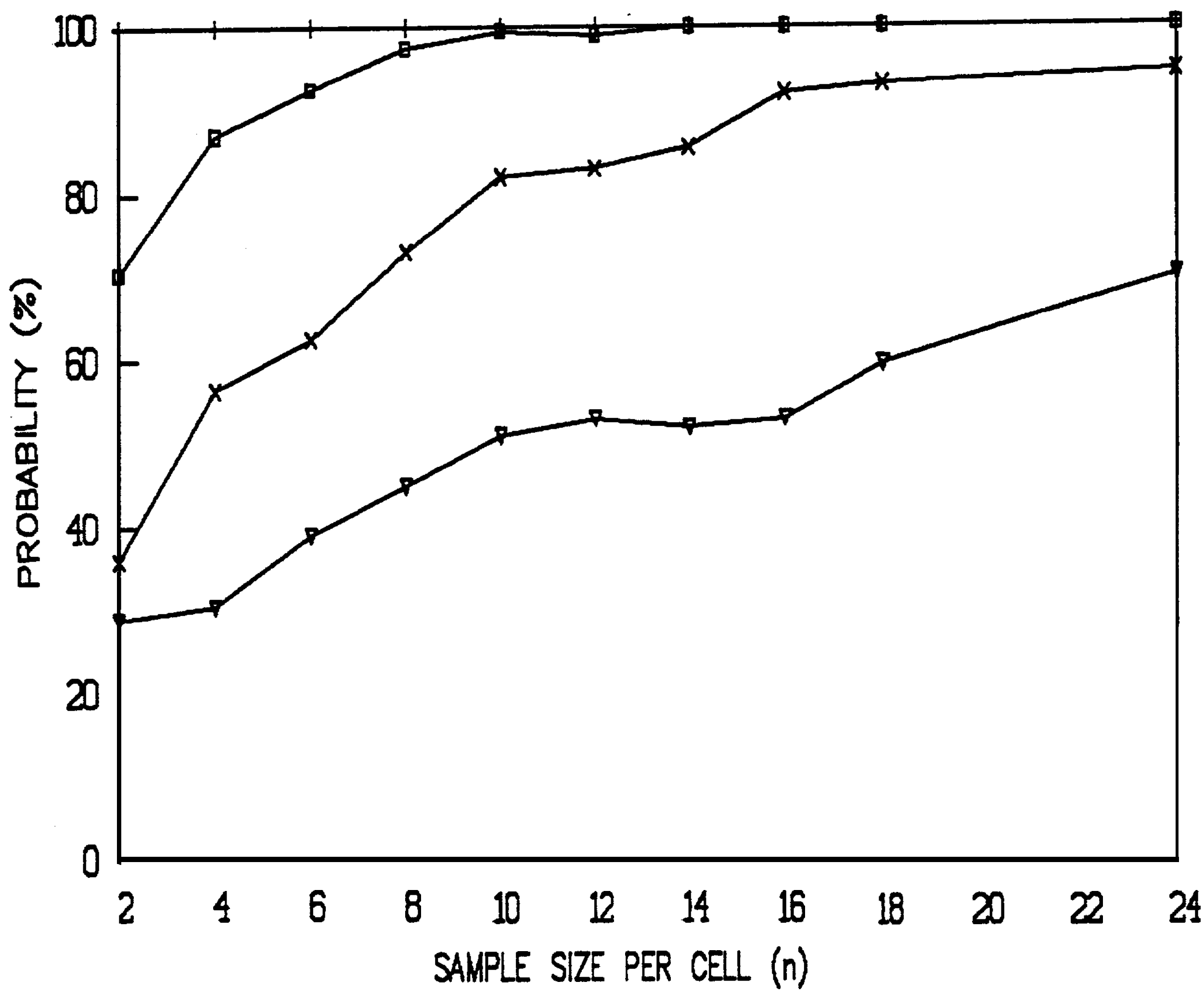



Appendix Figure A-1.5 Bottom gill net samples -- mean of non-zero catches. ( Percent difference population-sample (PD): + = PD ≤ 50%; ▮ = PD ≤20%; x= PD ≤ 10% ; inverted ▲= PD ≤ 5% )

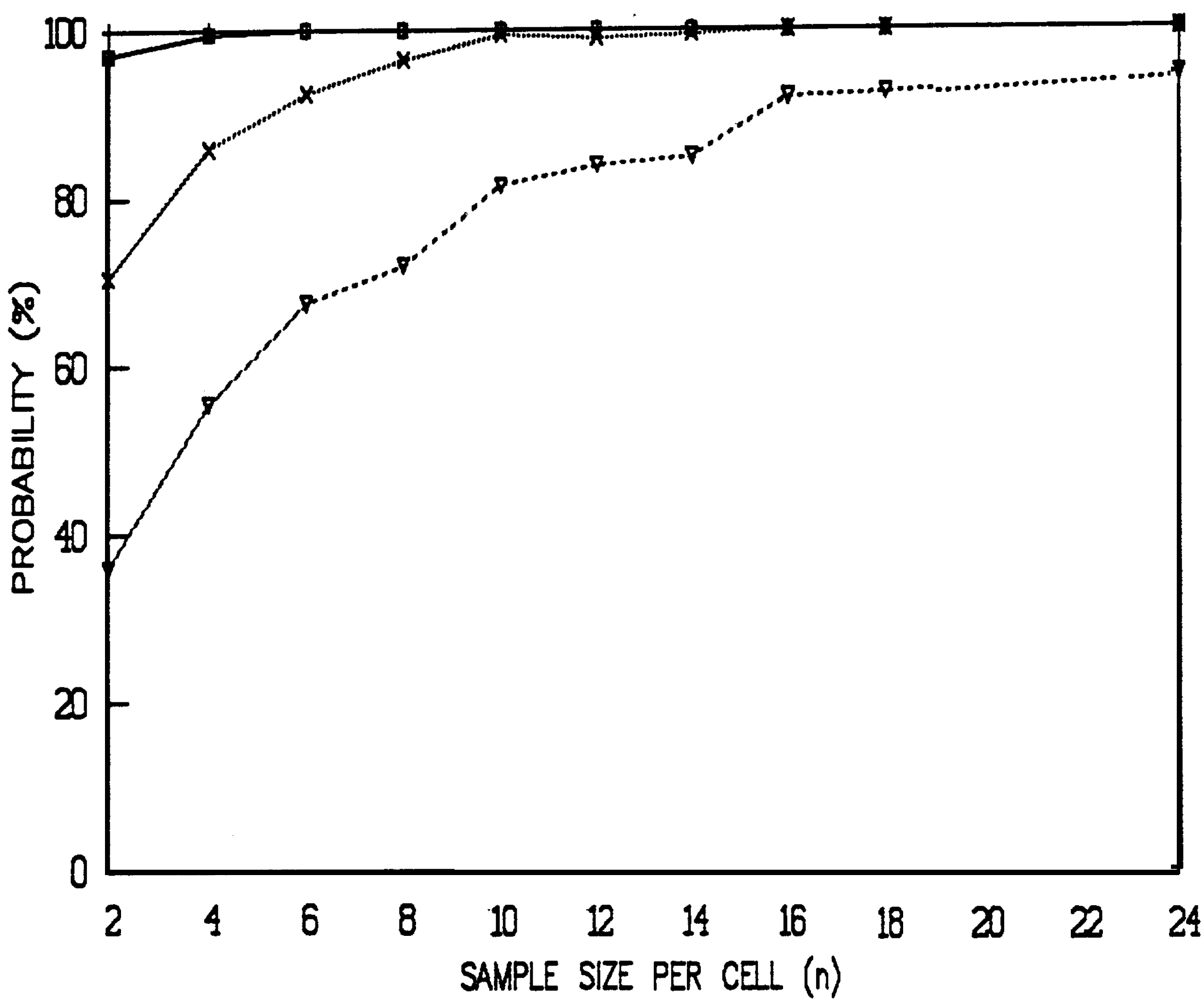



Appendix Figure A-1.6 Bottan gill net samples -- mean LN(non-zero catches). { Percent difference population-sample (PD): + = PD ≤ 50%; ▮ = PD ≤20%; x= PD ≤ 10% ; inverted ▲= PD ≤ 5% }

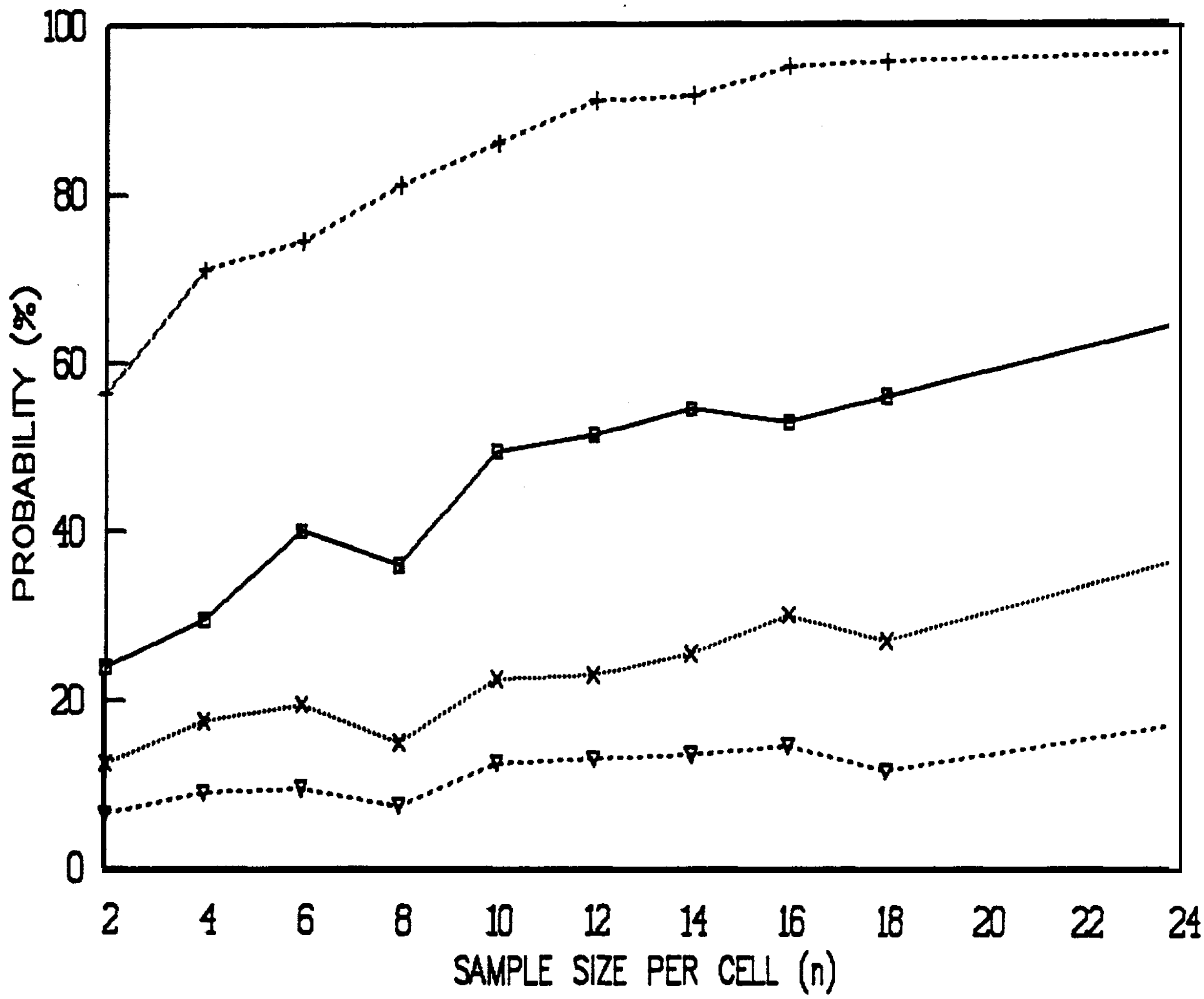
**Appendix A-2. Bootstrap analysis of six CPUE indices for boat electroshocker samples based on the proposed spatio-temporal sampling design (3 areas, 2 times); and comparing the statistical efficacy of varying sample size per replicate (2 to 24) -- from 200 random samples of data from John Day Reservoir during 1984-1986.**



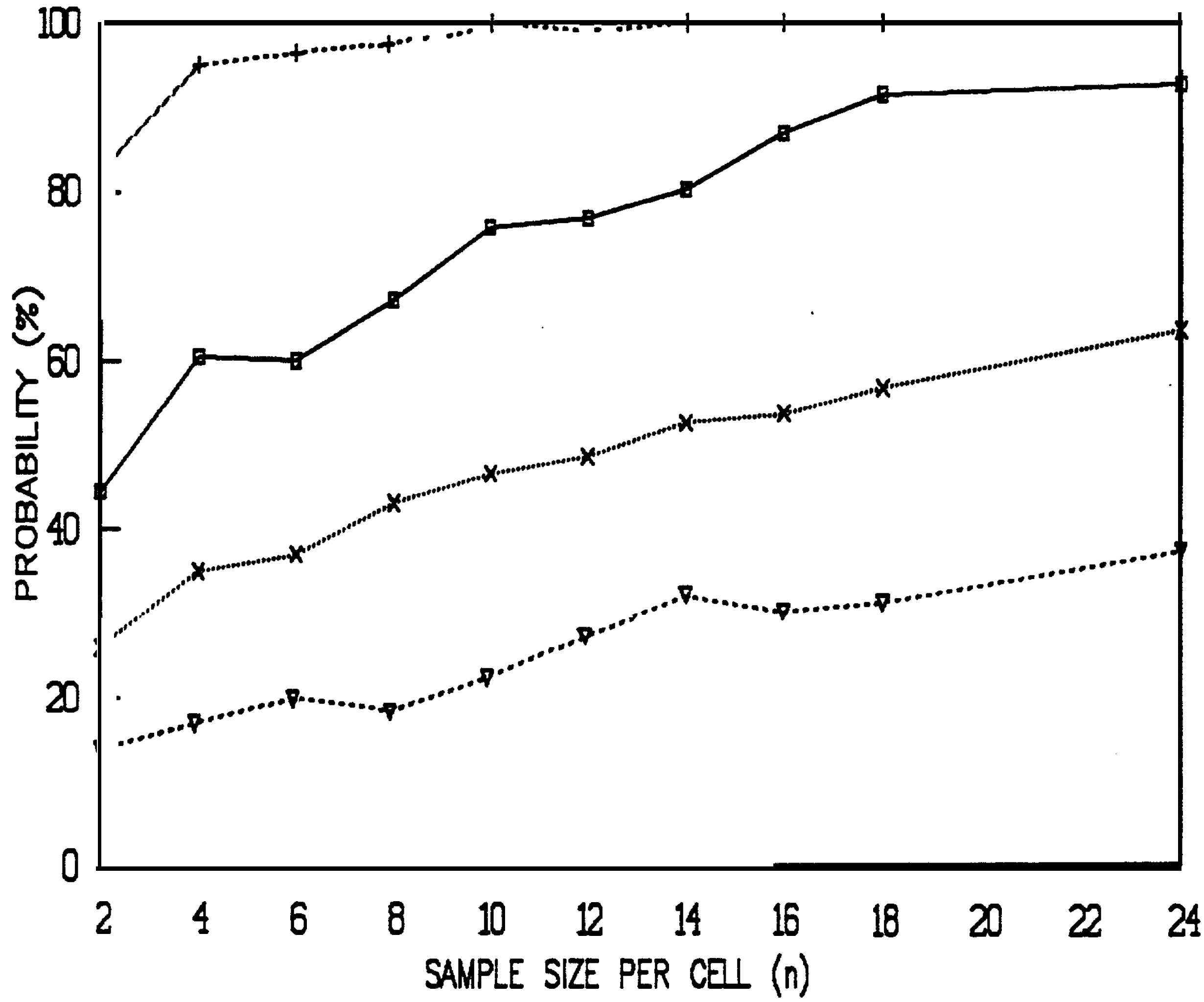

Appendix Figure A-2.1 Boat electroshocker samples -- percent zero catches. { Percent difference population-sample (PD): + = PD ≤ 50%; ▮ = PD ≤20%; x= PD ≤ 10% ; inverted ▲= PD ≤ 5% }



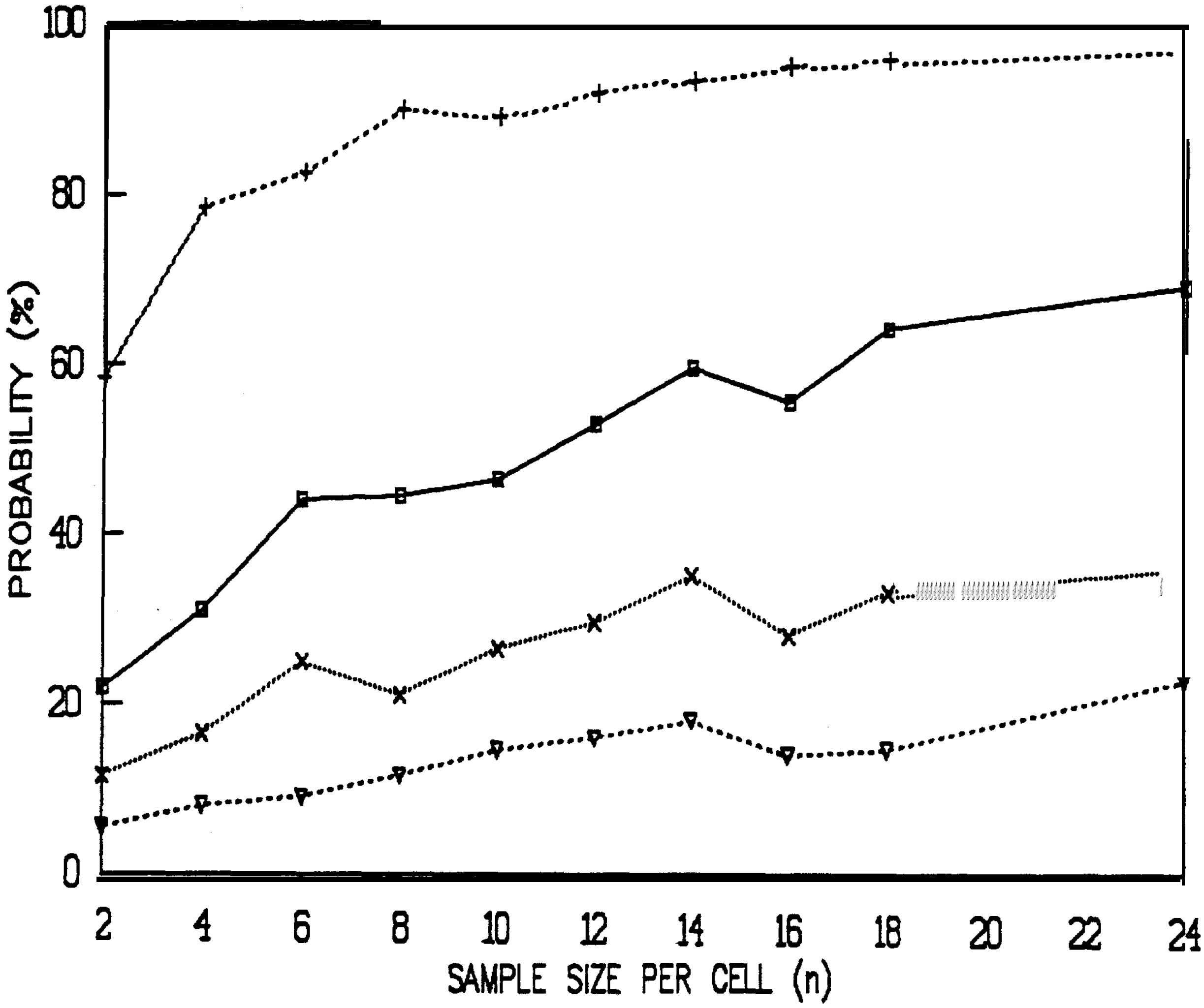

Appendix Figure A-2.2 Boat electroshocker samples -- square root (percent zero catches). ( Percent difference population-sample (PD): + = PD ≤ 50%; ▌ = PD ≤20%; x= PD ≤ 10% ; inverted ▲= PD ≤ 5% )



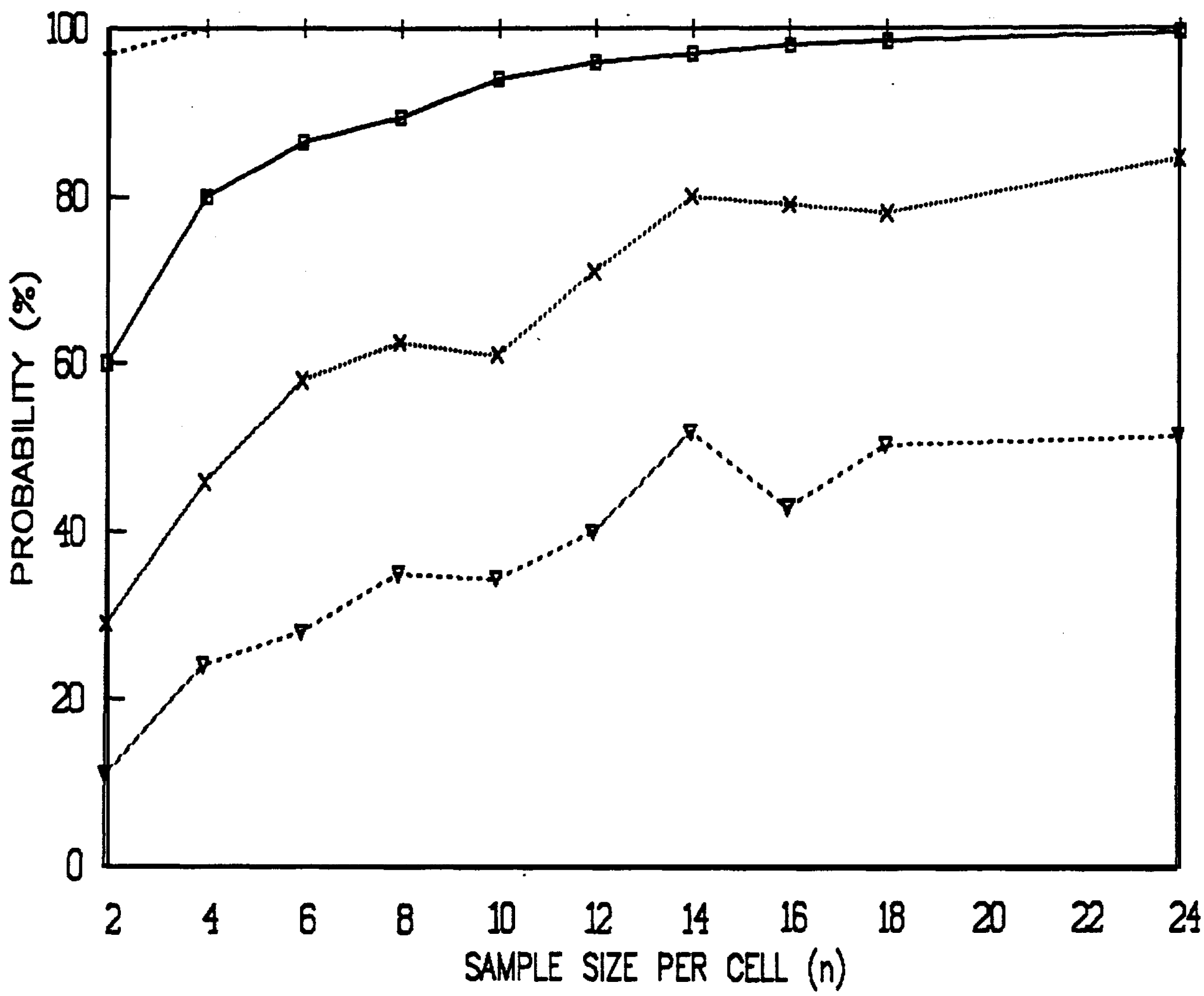

Appendix Figure A-2.3 Boat electroshocker samples -- mean of all catches. { Percent difference population-sample cm): + = PD ≤ 50%; ▮ = PD ≤20%; x= m ≤ 10% ; inverted ▲= PD ≤ 5% }




Appendix Figure A-2.4 Boat electroshocker samples -- mean LN(all catches). C Percent difference population-sample (PD): + = m ≤ 50%; ▮ = m ≤20%; x= m ≤ 10% ; inverted ▴= m ≤ 5% )

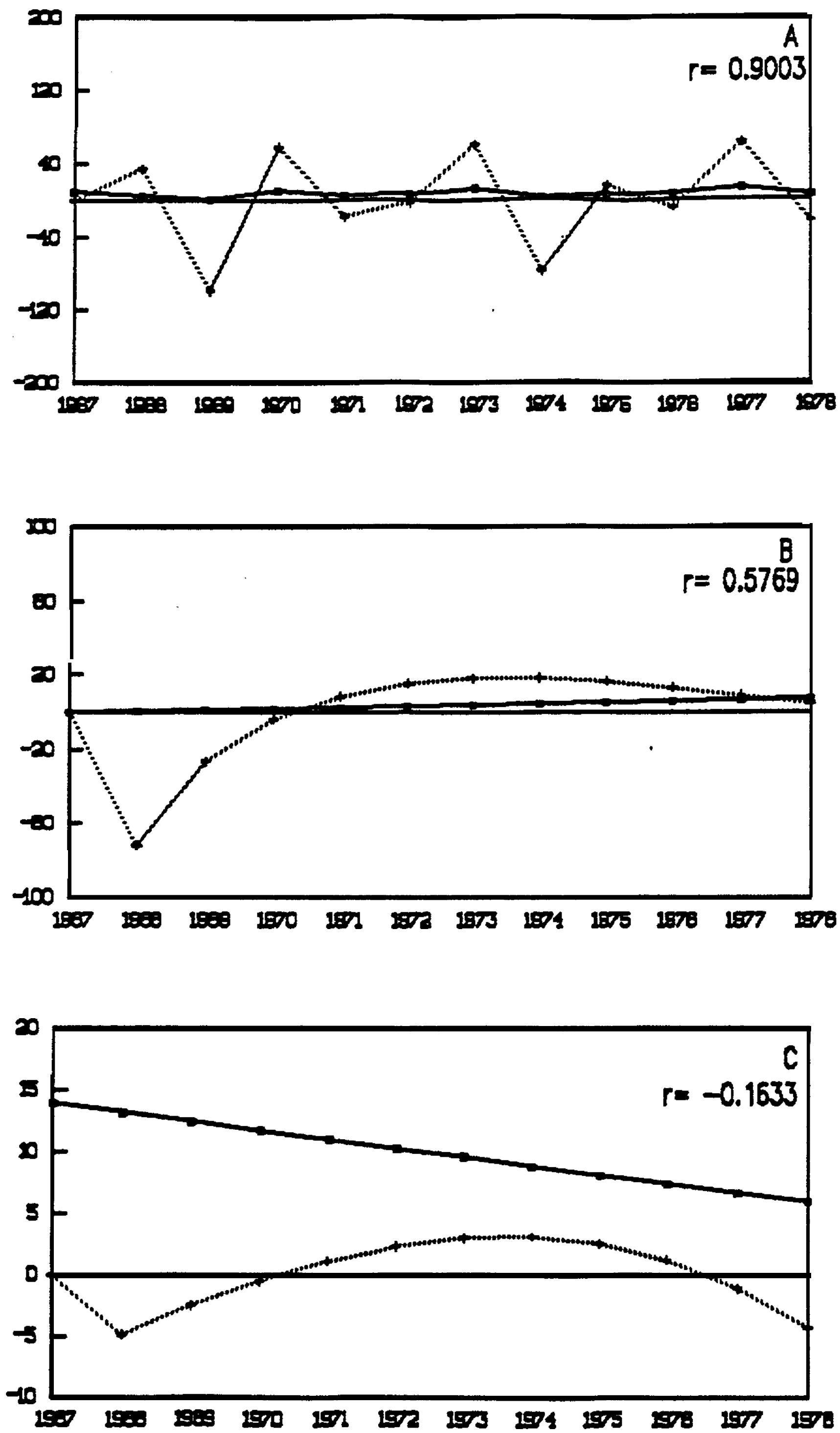



Appendix Figure A-2.5 Boat electroshocker samples -- mean of non-zero catches. ( Percent difference population-sample (PD): + = m ≤ 50%; ▮ = PD ≤20%; x= PD ≤ 10% ; inverted ▲= PD ≤ 5% )

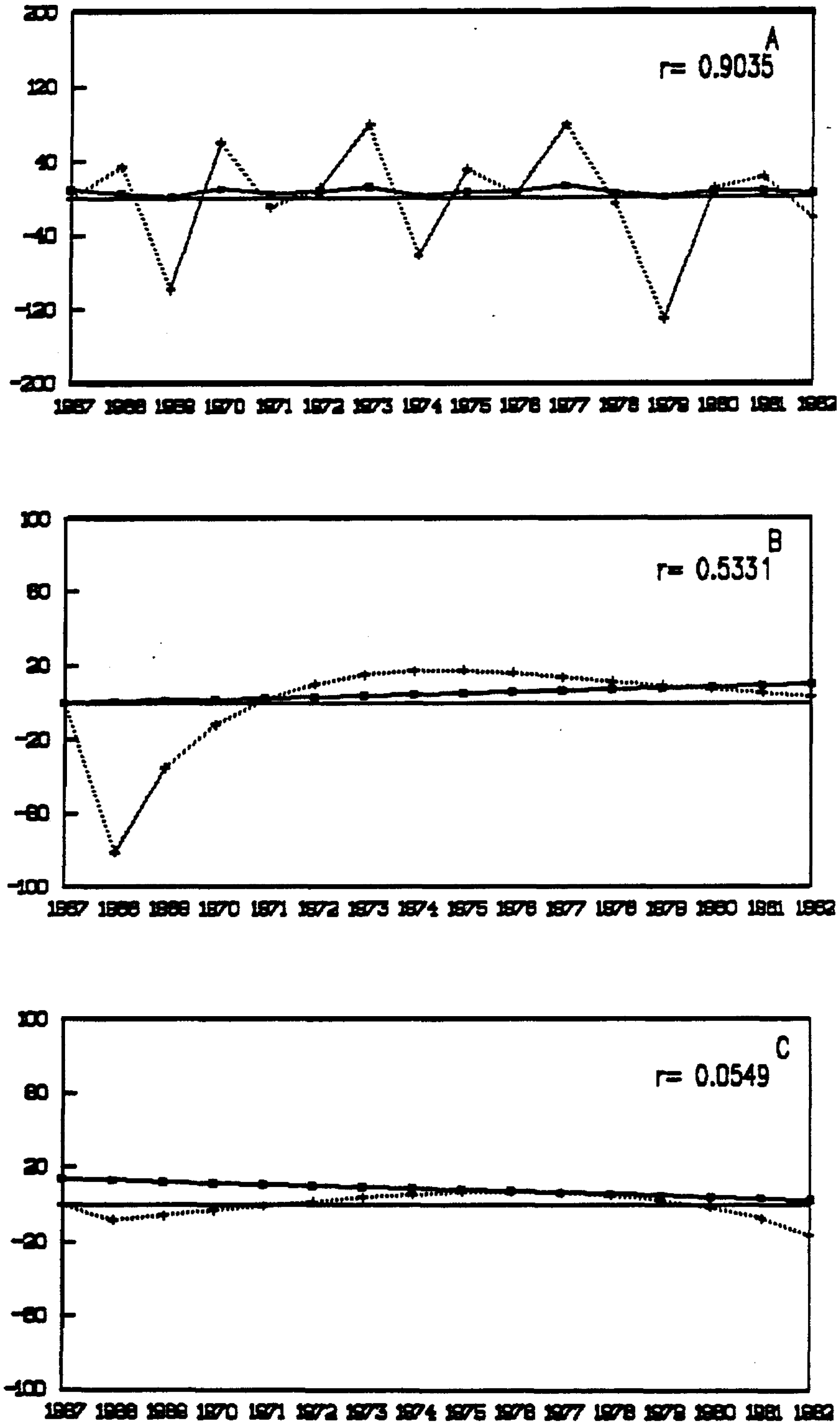



Appendix Figure A-2.6 Boat electroshocker samples -- mean LN(non-zero catches). { Percent difference population-sample (PD): + = PD ≤ 50%; ▮ = PD ≤20%; x= PD ≤ 10% ; inverted ▲= PD ≤ 5% }

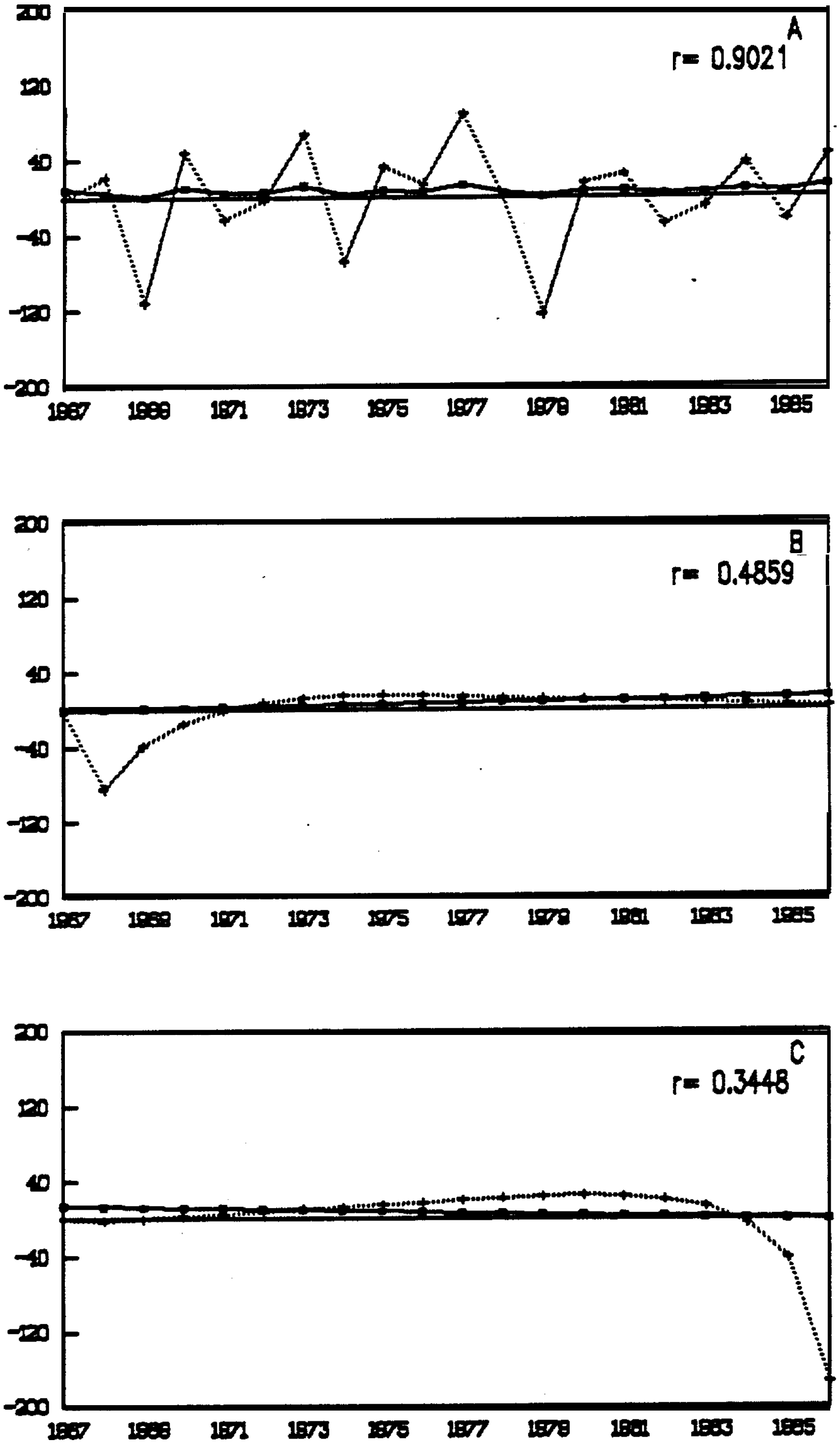
**Appendix** A-3. Figures *of* year-class **strength methods compared to theoretical population structures.**



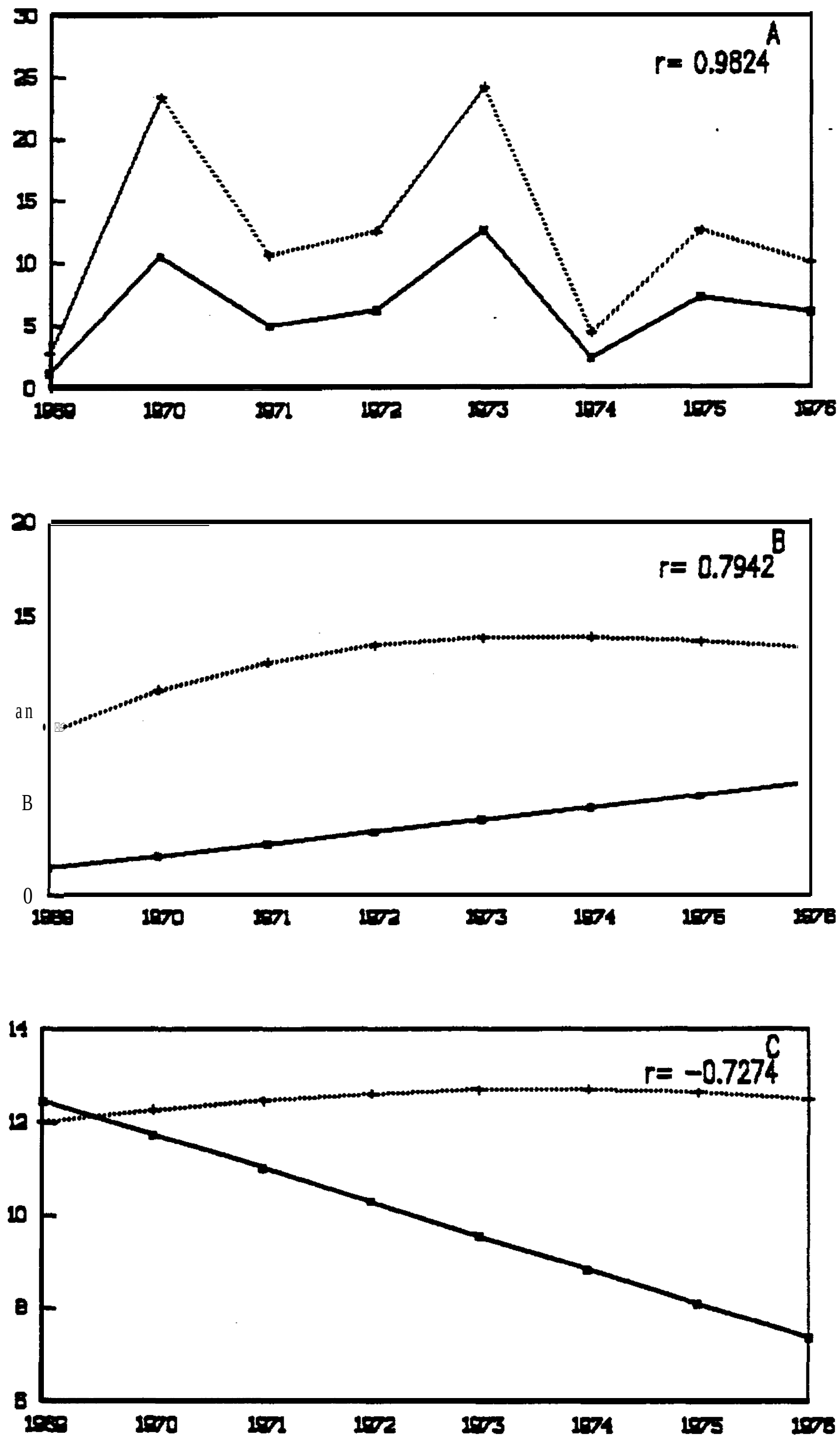

Appendix Figure A-3.1. El-Zarka method (3 yrs catch data) and the theoretical population data (percent) using the northern squawfish scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dotted Line = predicted values from the method, r = correlation coefficient.



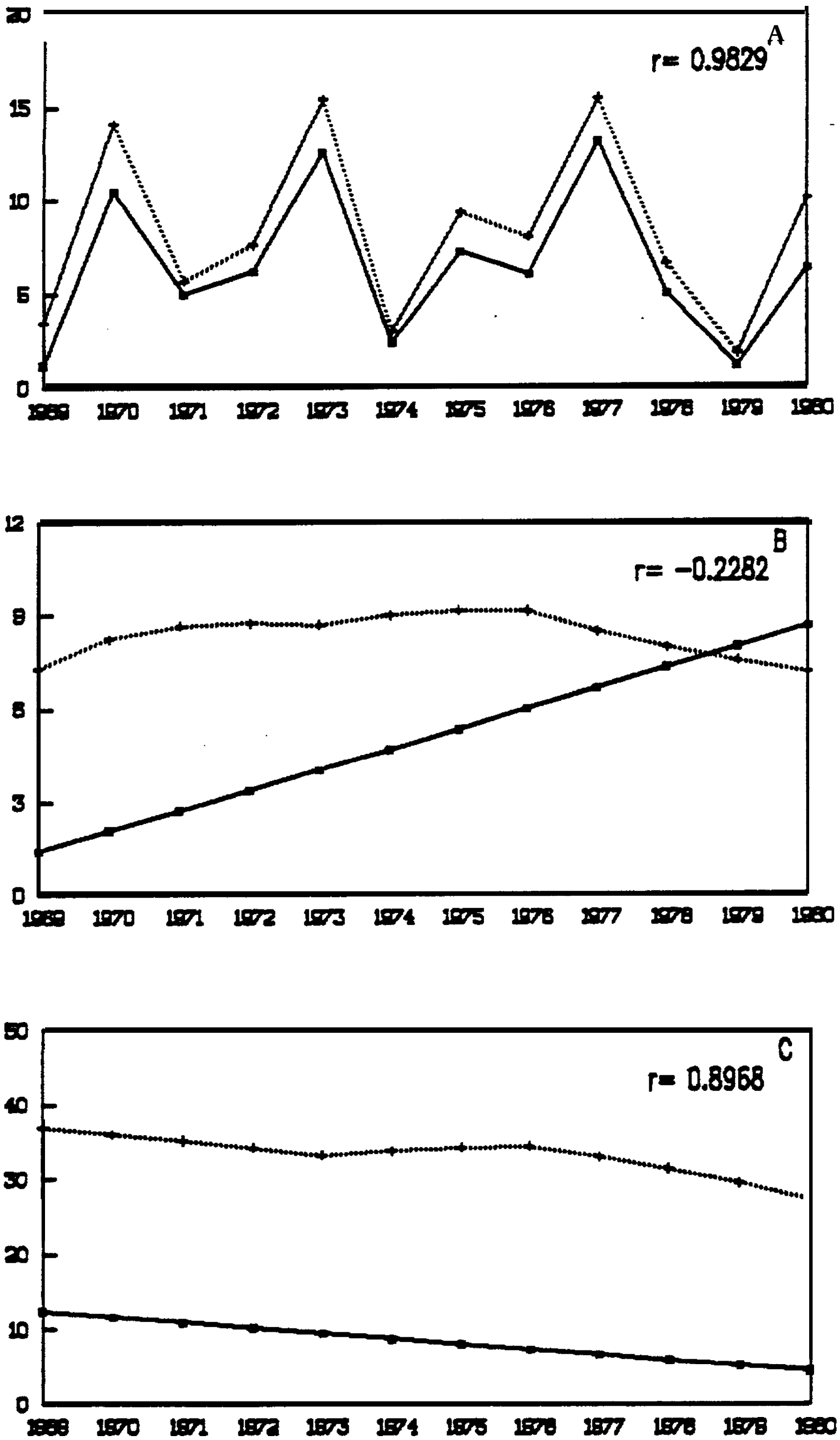

Appendix Figure A-3.2. EL-Zarka method (7 yrs catch data> and the theoretical population data (percent) using the northern squawfish scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dotted line = predicted values from the method, r = correlation coefficient.



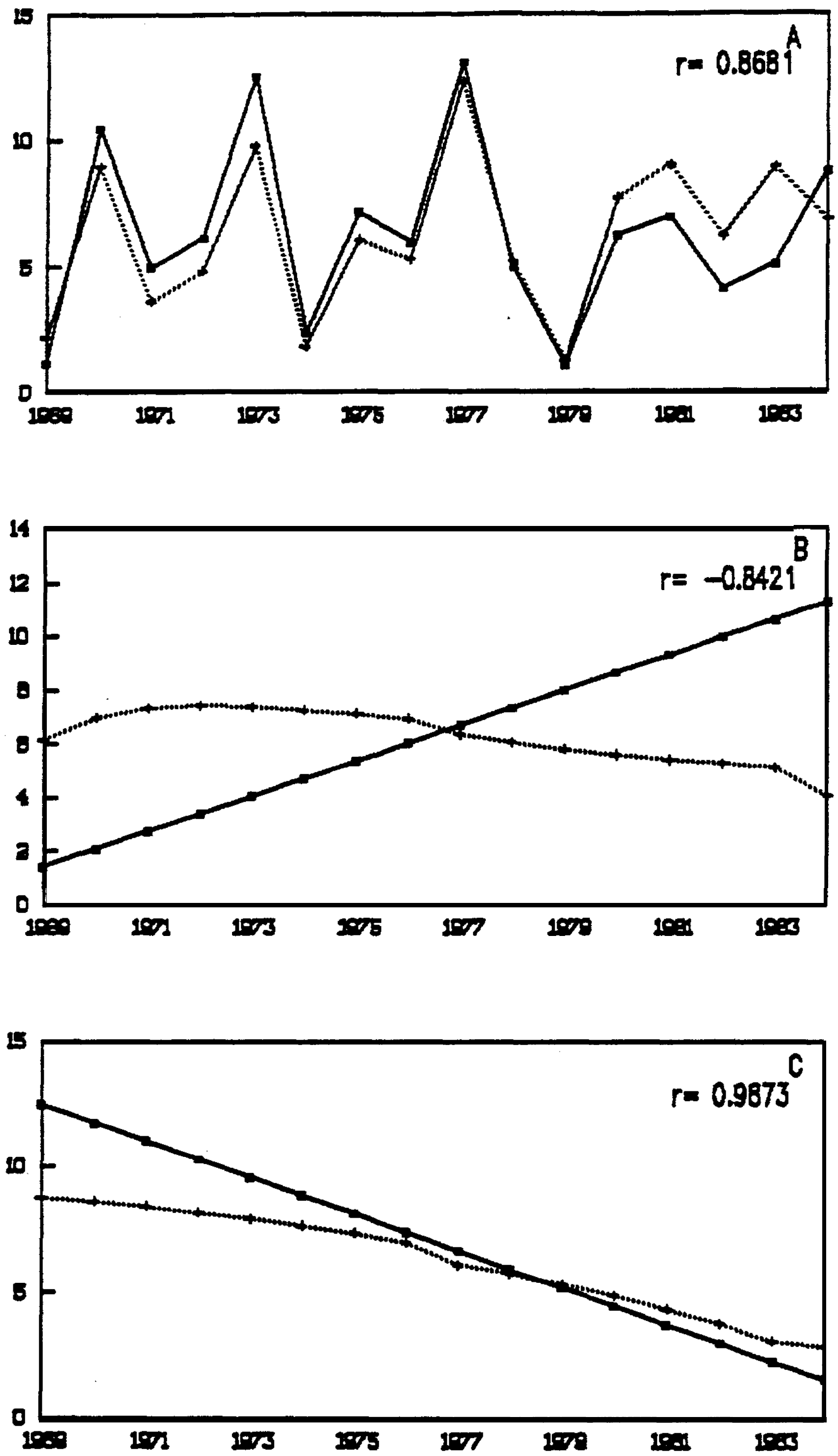

Appmdix Figure A-3.3. El-Zarka method (11 yrs catch data) and the theoretical population data (percent) using the northern squawfish scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dotted line = predicted values from the method, r= correlation coefficient.



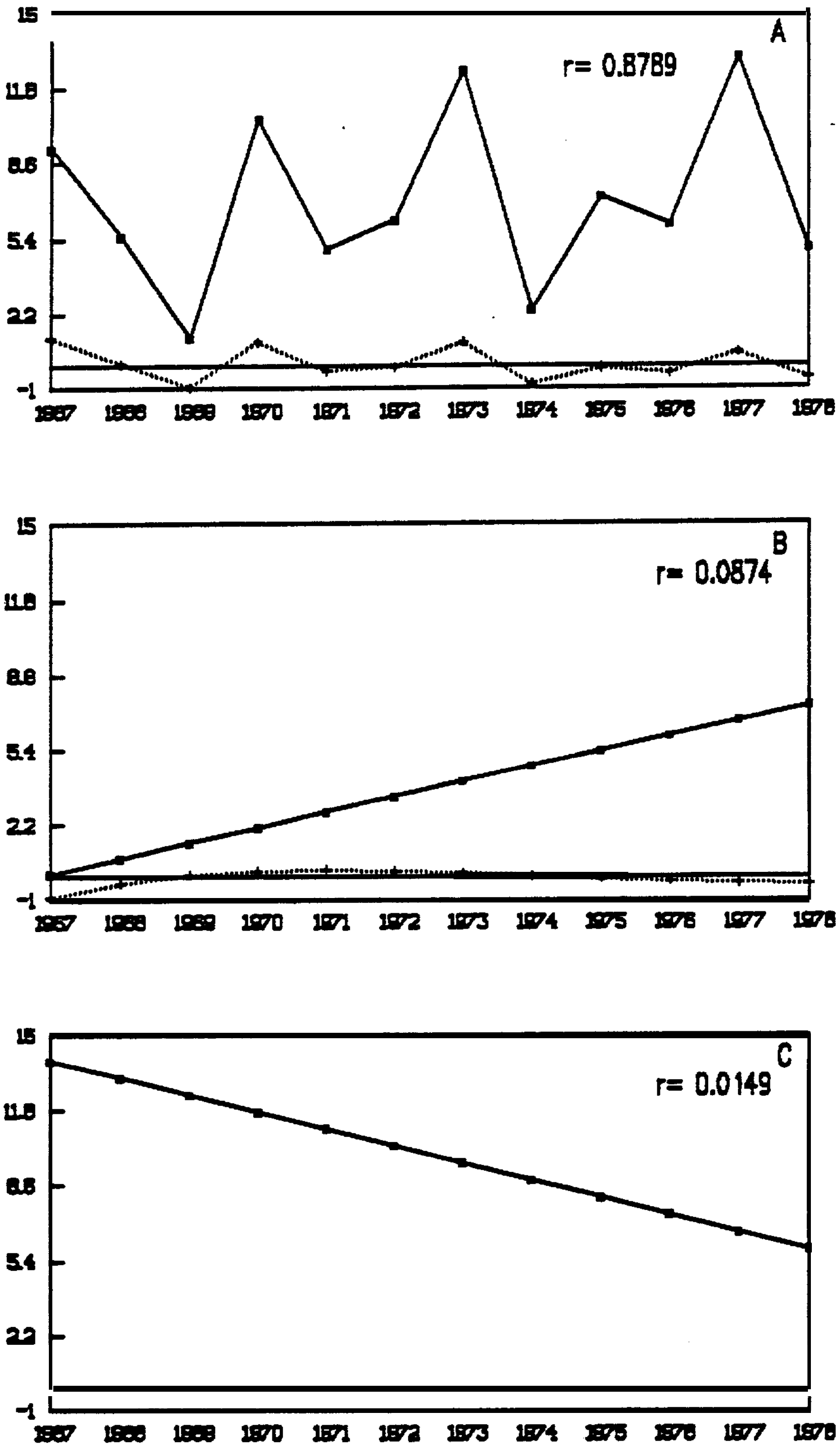

Appendix Figure A-3.4. Extrapolation method (3 yrs catch data) and the theoretical population data (percent) using the northern squaufish scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid Line = theoretical population, dotted line = predicted values from the method, r= correlation coefficient.



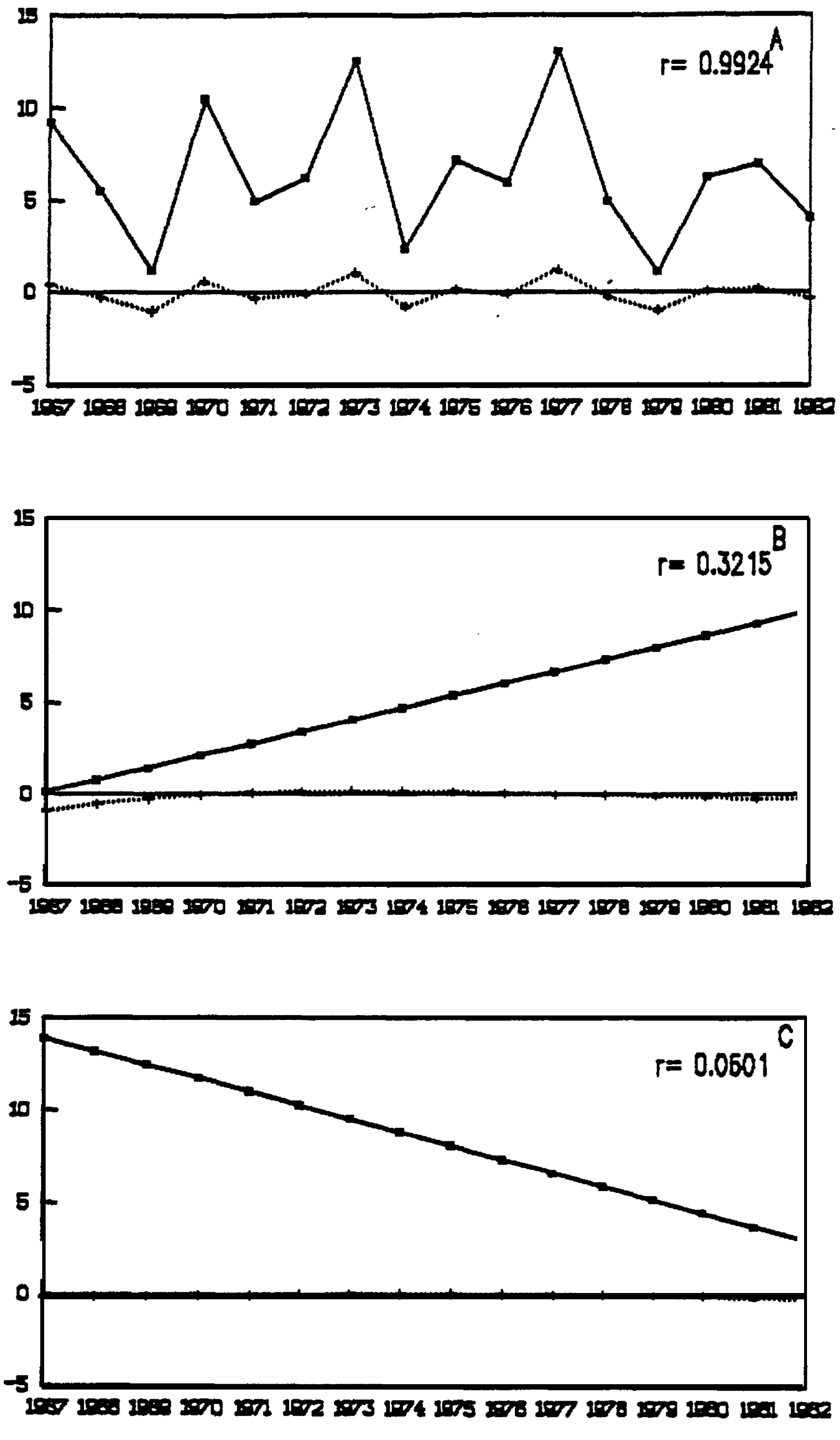

Appendix Figure A-3.5. Extrapolation method (7 yrs catch data) and the theoretical population data (percent) using the northern squawfish scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dotted line = predicted values from the method, r= correlation coefficient.



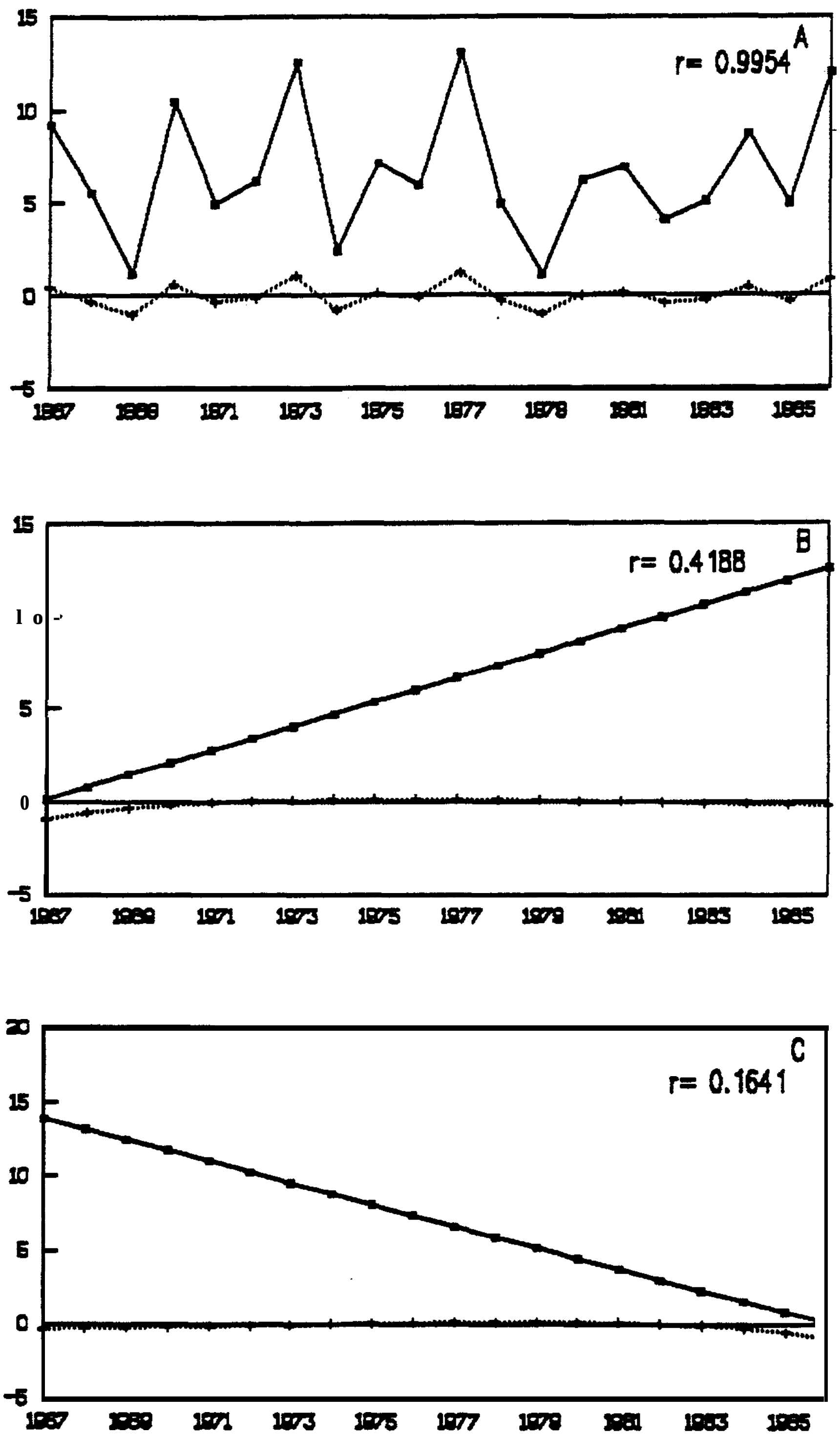

Appendix Figure A-3.6. Extrapolation method (11 yrs catch-data) and the theoretical population data (percent) using the northern squawfish scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dotted line = predicted values from the method, r= correlation coefficient.



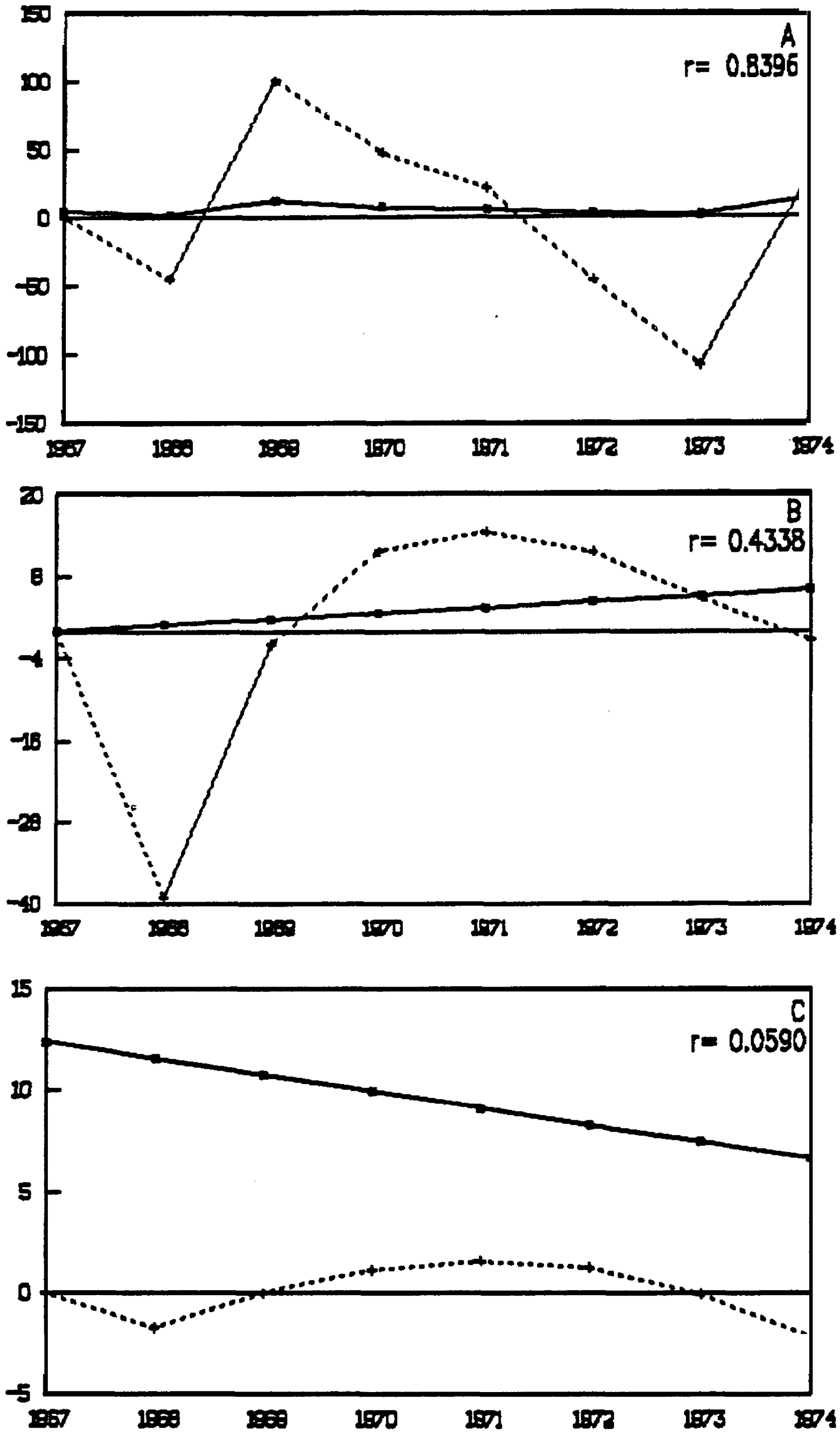

Appendix Figure A-3.7. Rieman method (3 yrs catch data) and the theoretical population data (percent) using the northern squawfish scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dotted line = predicted values from the method, r= correlation coefficient.



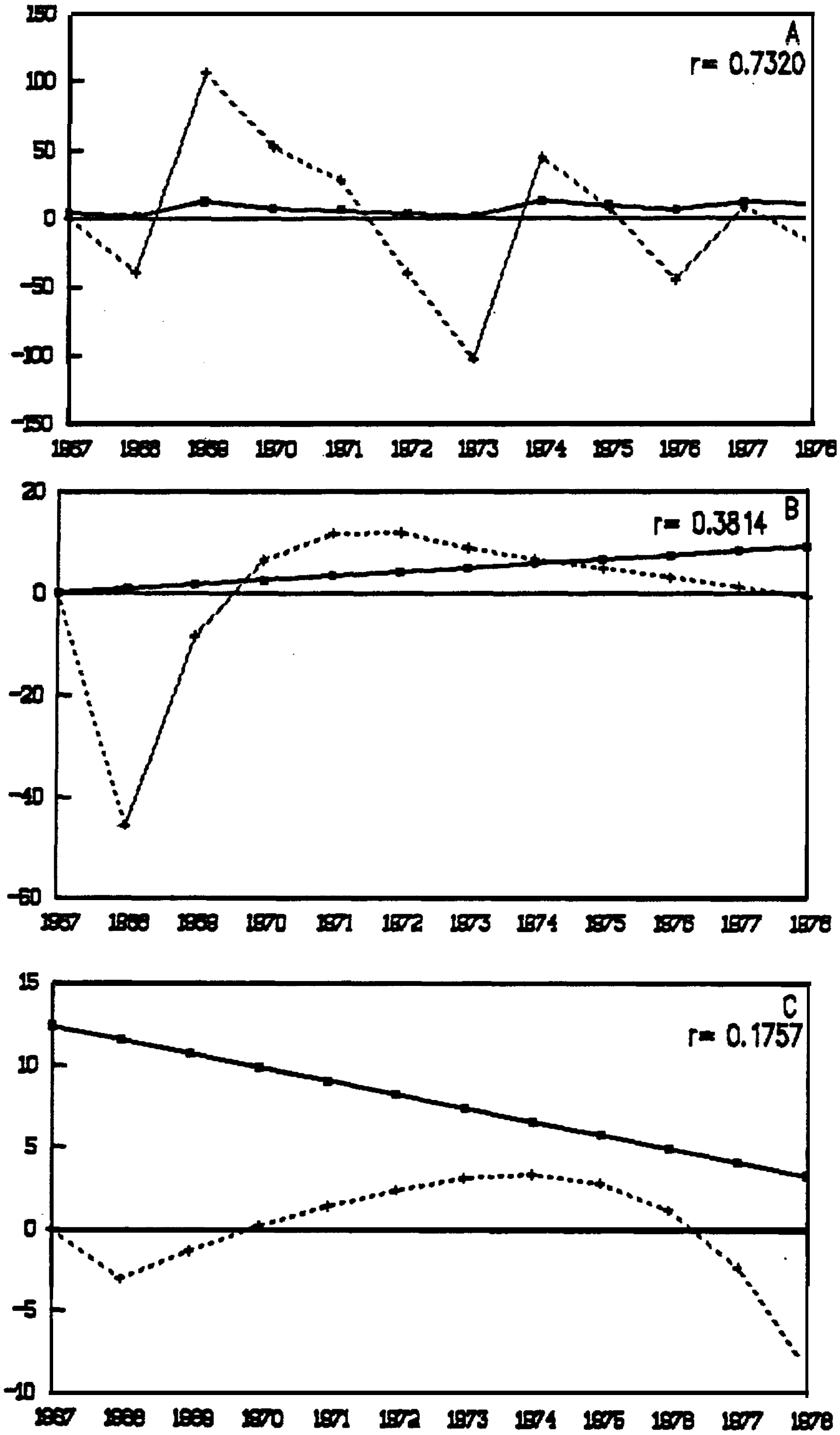

Appendix Figure A-3.8. Rieman method (7 yrs catch data) and the theoretical population data (percent) using the northern squaufish scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dotted line = predicted values from the method, r= correlation coefficient.



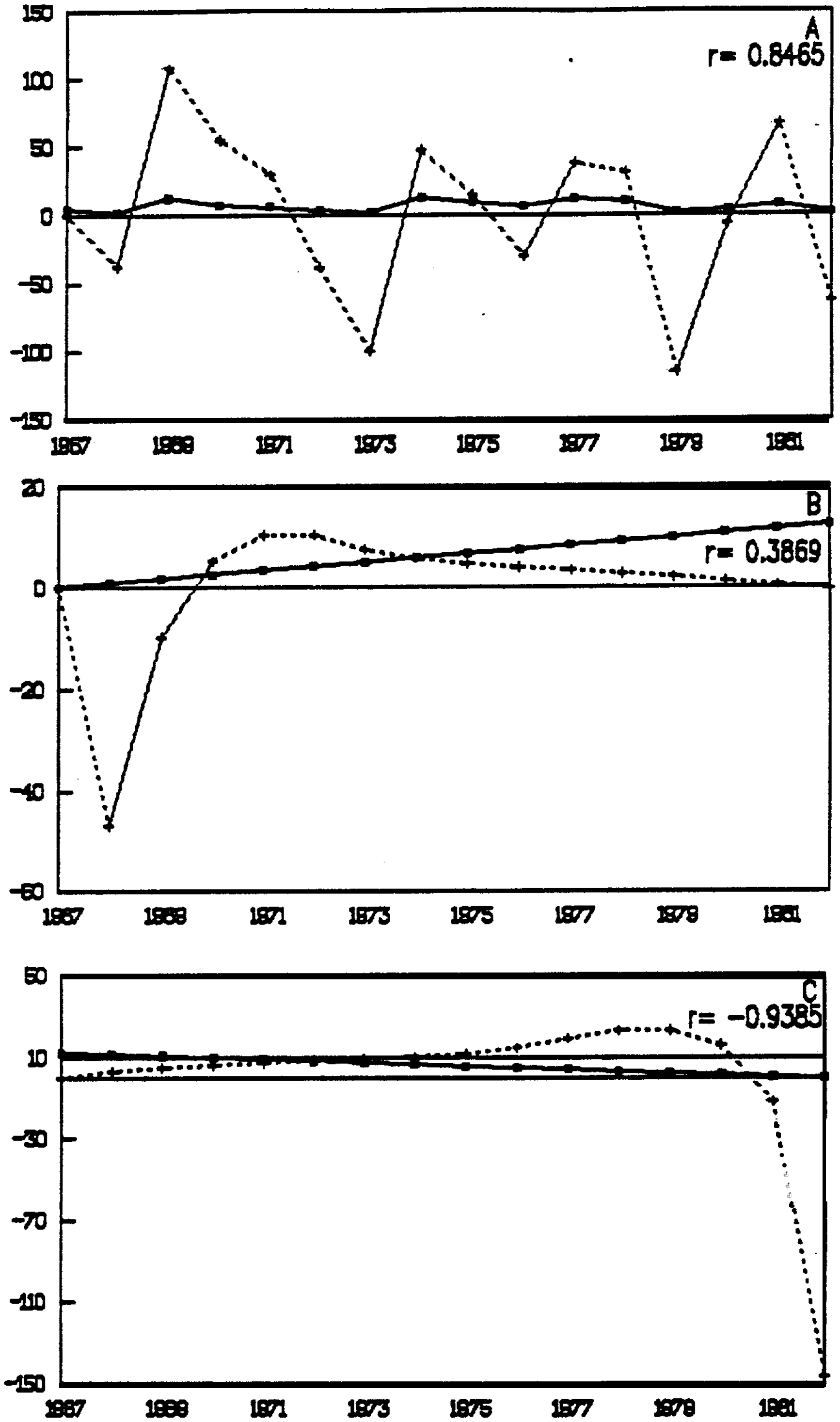

Appendix Figure A-3.9. Rieman method (11 yrs catch data) and the theoretical population data (percent) using the northern squawfish scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dotted line = predicted values from the method, r= correlation coefficient.



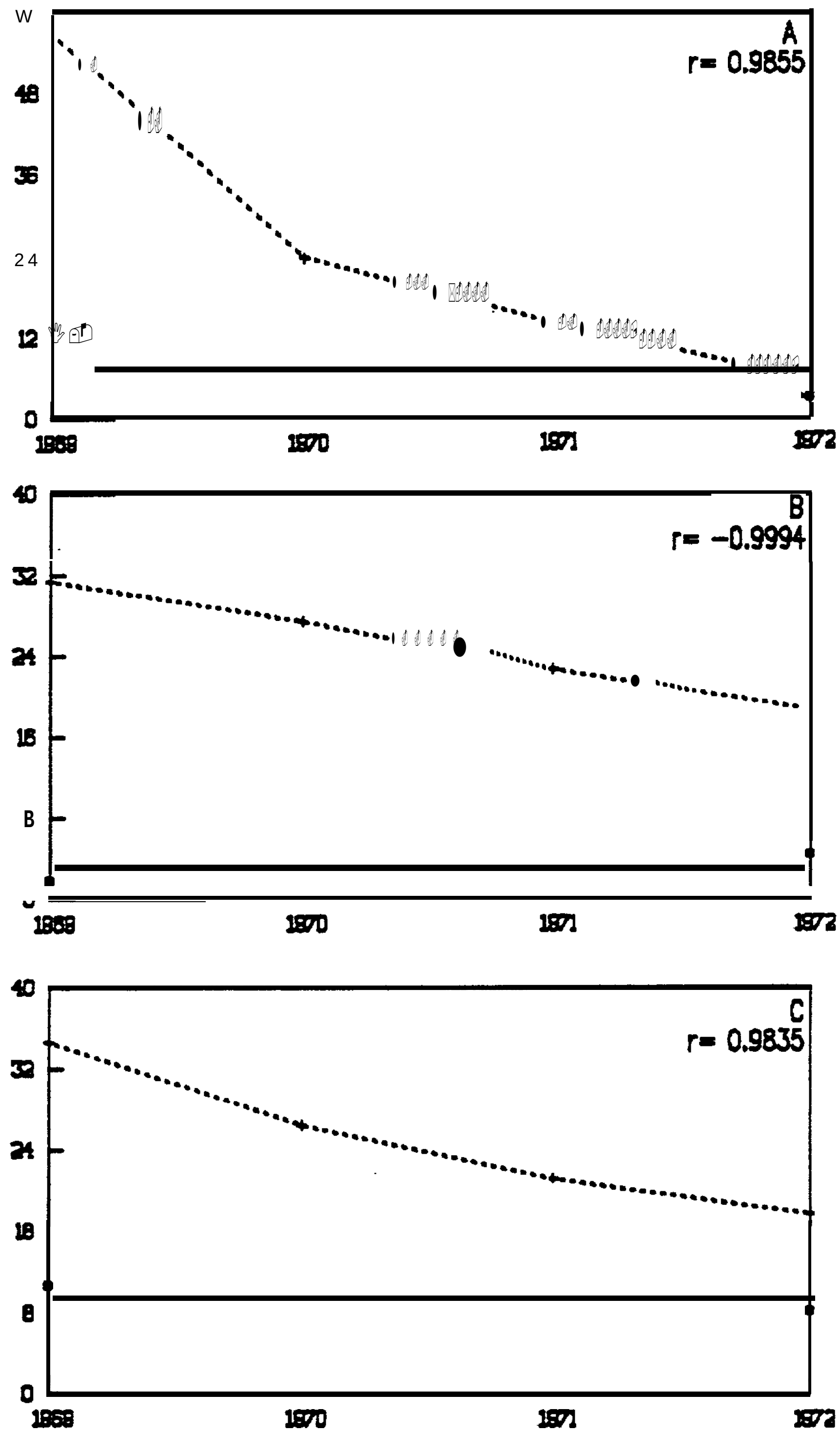

Appendix Figure A-3.10. El-Zarka method (3 yrs catch data] and the theoretical population (percent) using the walleye scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dashed line = predicted values from the method, r = correlation coefficient.



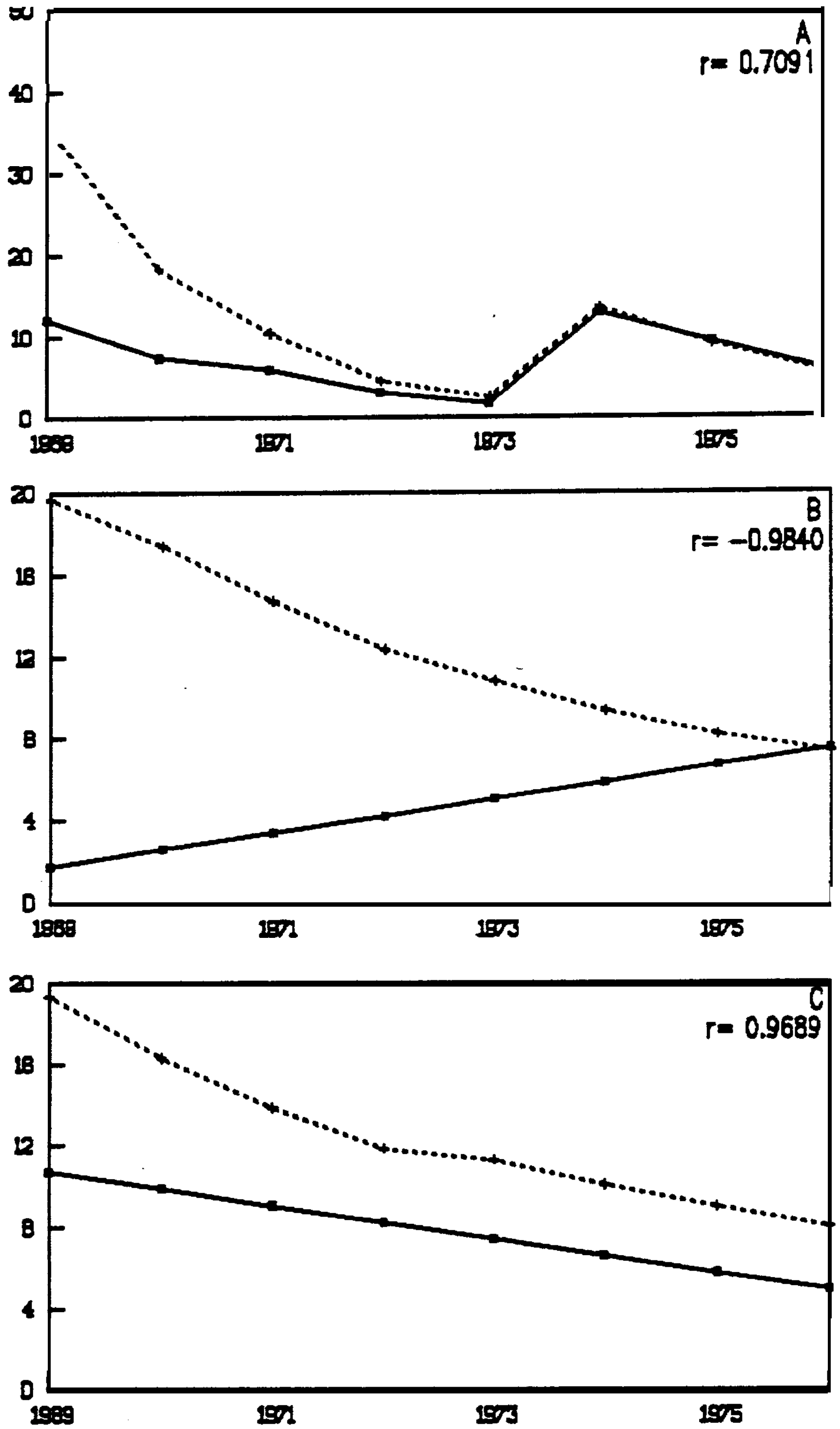

Appendix Figure A-3.11. El-Zarka method (7 yrs catch data) and the theoretical population data (percent) using the ualleye scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dashed line = predicted values from the method, r = correlation coefficient.



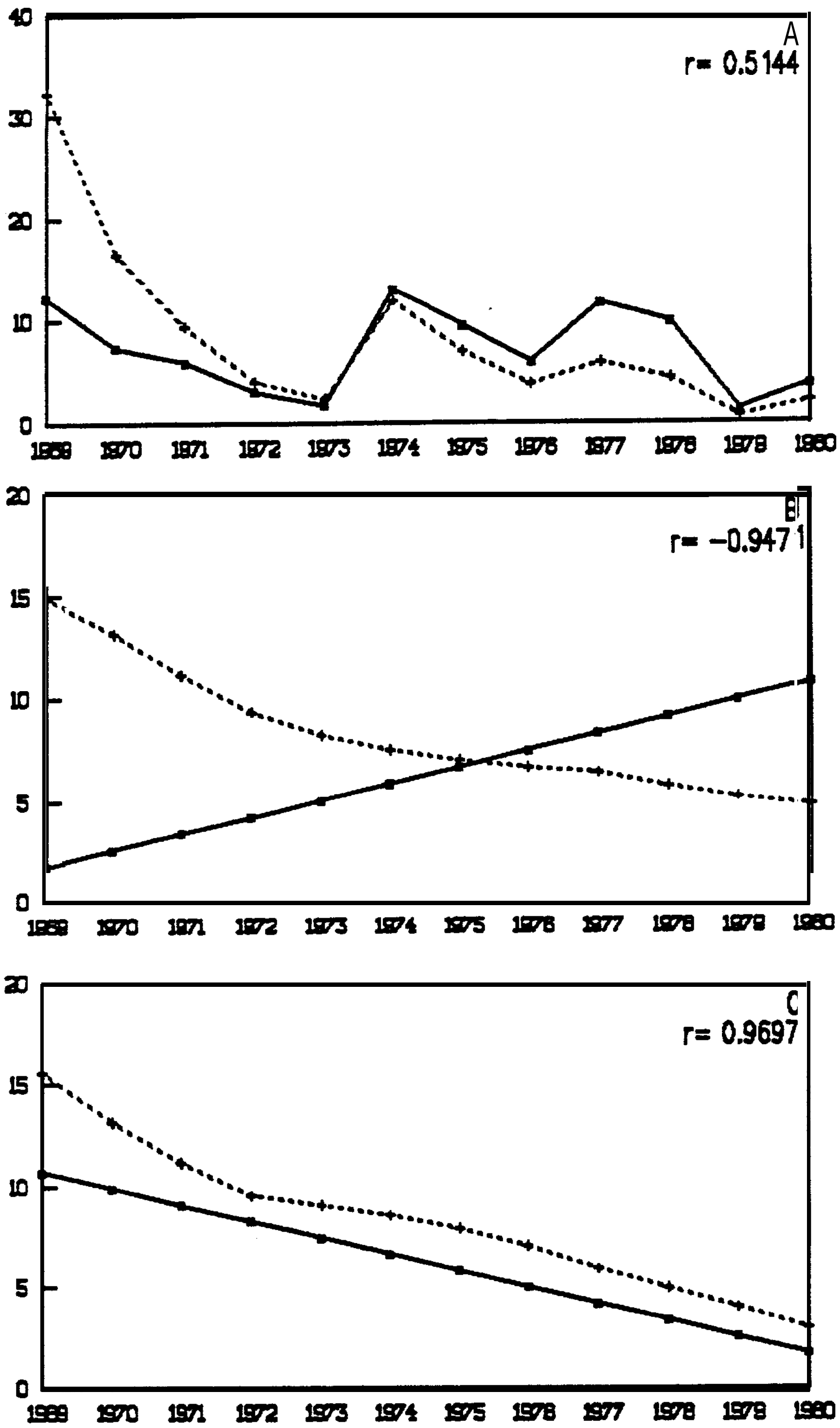

Appendix Figure A-3.12. El-Zarka method (11 yrs catch data) and the theoretical population data (percent) using the walleye life history scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dashed line = predicted values from the method, r= correlation coefficient.



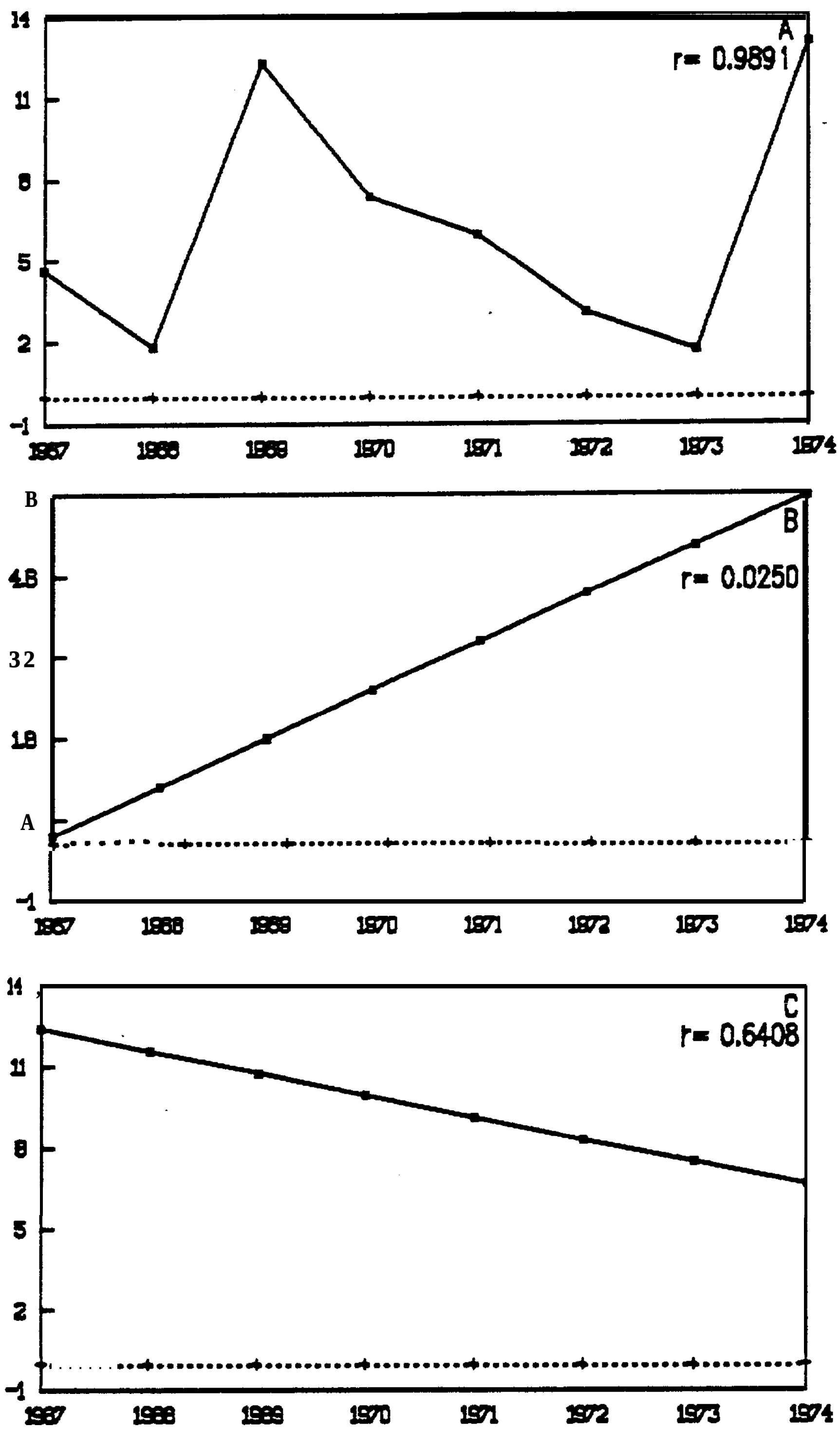

Appendix Figure A-3.13. Extrapolation method (3 yrs catch-data) and the theoretical population data (percent) using the walleye life history scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dashed line = predicted values from the method, r= correlation coefficient.



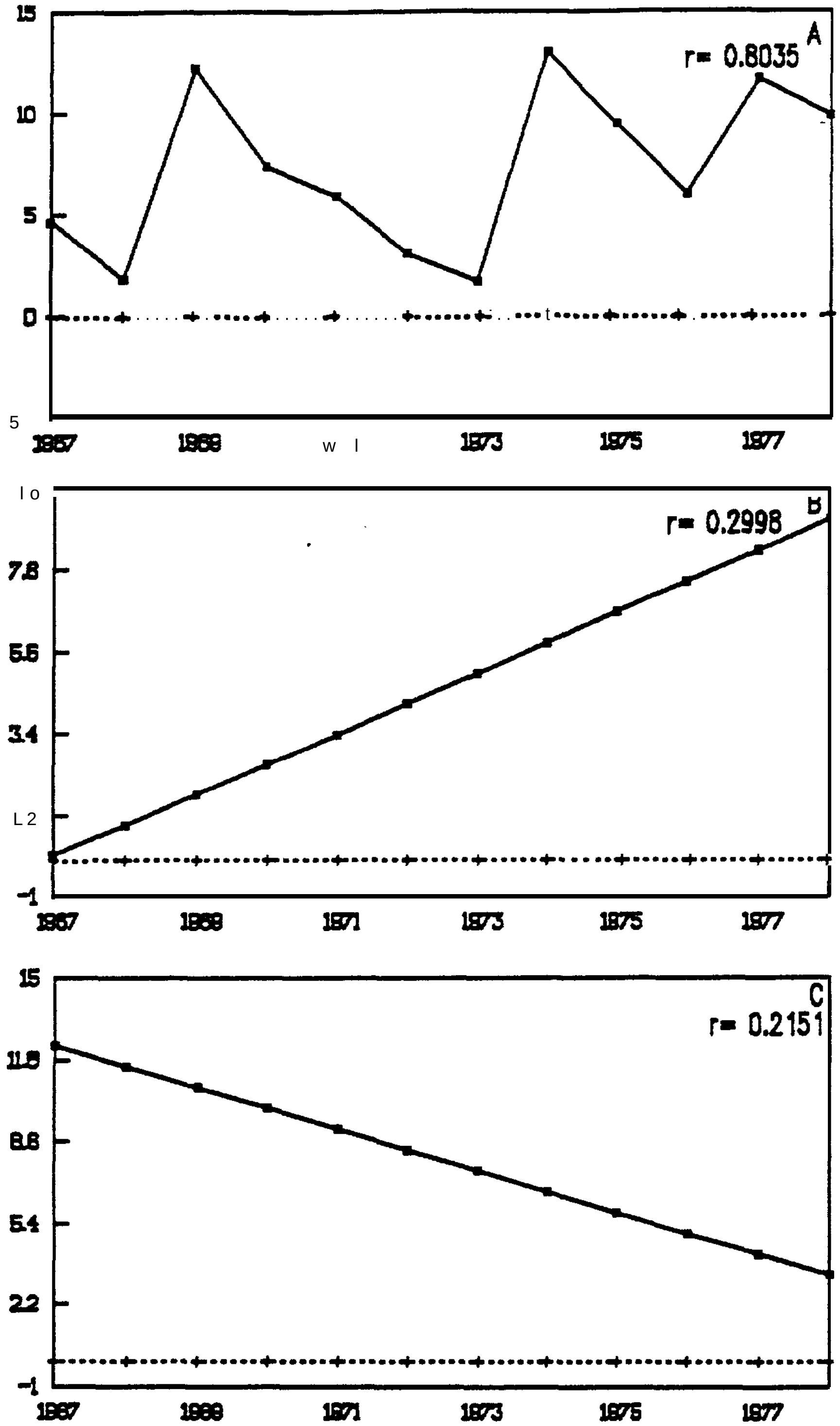

Appendix Figure A-3.14. Extrapolation method (7 yrs catch-data) and the theoretical population data (percent) using the walleye Life history scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid Line = theoretical population, dashed line = predicted values from the method, r= correlation coefficient.



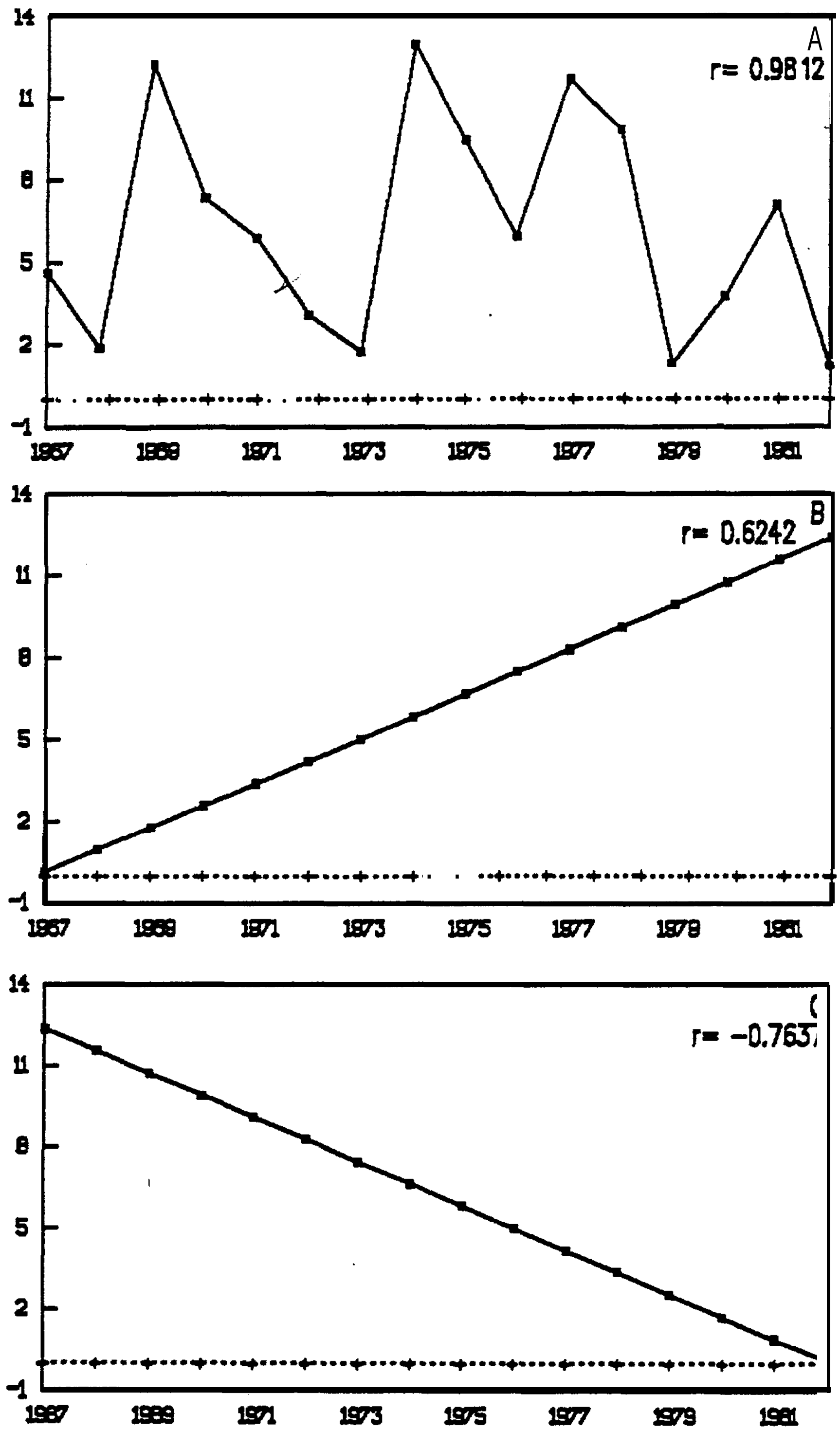

Appendix Figure A-3.15. Extrapolation method (11 yrs catch data) and the theoretical population data (percent) using the walleye life history scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dashed line = predicted values from the method, r= correlation coefficient.




Appendix Figure A-3.16. Rieman method (3 yrs catch data) and the theoretical population data (percent) using the walleye Life history scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dashed line = predicted values from the method, r= correlation coefficient.




Appendix Figure A-3.17. **Rieman** method (7 yrs catch **data)** **and** the theoretical population data (percent) using the walleye life history scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, dashed line = predicted values from the method, r= correlation coefficient.




Appendix Figure A-3.18. Rieman method (11 yrs catch data) and the theoretical population data (percent) using the walleye life history scenario. A = random, B = increasing trend and C = decreasing trend in theoretical population structures. Solid line = theoretical population, clashed line = predicted values from the method, r= correlation coefficient.

APPENDIX A-4. Precision estimate data using three replicate aging of each northern squawfish (n= 153) by one reader.

| Fish # | Replicates 1st | 2nd | 3rd | Average age | APE | CV |
|---|---|---|---|---|---|---|
| 12 | 4 | 4 | 4 | 4 | 0 | 0 |
| 9 | 4 | 5 | 5 | 4.6667 | 0.0952 | 0.1237 |
| 84 | 5 | 5 | 4 | 4.6667 | 0.0952 | 0.1237 |
| 8 | 5 | 5 | 5 | 5 | 0 | 0 |
| 23 | 5 | 6 | 4 | 5 | 0.1333 | 0.2 |
| 137 | 5 | 5 | 5 | 5 | 0 | 0 |
| 19 | 5 | 6 | 5 | 5.3333 | 0.0833 | 0.1082 |
| 20 | 5 | 6 | 5 | 5.3333 | 0.0833 | 0.1082 |
| 106 | 5 | 5 | 6 | 5.3333 | 0.0833 | 0.1082 |
| 111 | 6 | 5 | 5 | 5.3333 | 0.0833 | 0.1082 |
| 10 | 6 | 6 | 5 | 5.6667 | 0.0784 | 0.1018 |
| 21 | 5 | 7 | 5 | 5.6667 | 0.1569 | 0.2037 |
| 36 | 6 | 6 | 5 | 5.6667 | 0.0784 | 0.1018 |
| 69 | 6 | 6 | 5 | 5.6667 | 0.0784 | 0.1018 |
| 79 | 6 | 6 | 5 | 5.6667 | 0.0784 | 0.1018 |
| 91 | 6 | 6 | 5 | 5.6667 | 0.0784 | 0.1018 |
| 105 | 6 | 6 | 5 | 5.6667 | 0.0784 | 0.1018 |
| 144 | 6 | 5 | 6 | 5.6667 | 0.0784 | 0.1018 |
| 163 | 6 | 6 | 5 | 5.6667 | 0.0784 | 0.1018 |
| 3 | 5 | 7 | 6 | 6 | 0.1111 | 0.1666 |
| 4 | 5 | 7 | 6 | 6 | 0.1111 | 0.1666 |
| 5 | 6 | 6 | 6 | 6 | 0 | 0 |
| 7 | 6 | 6 | 6 | 6 | 0 | 0 |
| 17 | 6 | 6 | 6 | 6 | 0 | 0 |
| 31 | 6 | 7 | 5 | 6 | 0.1111 | 0.1666 |
| 73 | 6 | 6 | 6 | 6 | 0 | 0 |
| 78 | 6 | 7 | 5 | 6 | 0.1111 | 0.1666 |
| 82 | 5 | 7 | 6 | 6 | 0.1111 | 0.1666 |
| 99 | 6 | 6 | 6 | 6 | 0 | 0 |
| 124 | 6 | 6 | 6 | 6 | 0 | 0 |
| 147 | 7 | 6 | 5 | 6 | 0.1111 | 0.1666 |
| 153 | 6 | 6 | 6 | 6 | 0 | 0 |
| 159 | 6 | 6 | 6 | 6 | 0 | 0 |
| 30 | 6 | 8 | 5 | 6.3333 | 0.1754 | 0.2411 |
| 64 | 7 | 7 | 5 | 6.3333 | 0.1404 | 0.1823 |
| 76 | 7 | 8 | 4 | 6.3333 | 0.2456 | 0.3286 |
| 81 | 7 | 6 | 6 | 6.3333 | 0.0702 | 0.0911 |
| 94 | 7 | 6 | 6 | 6.3333 | 0.0702 | 0.0911 |
| 98 | 7 | 7 | 5 | 6.3333 | 0.1404 | 0.1823 |
| 123 | 8 | 6 | 5 | 6.3333 | 0.1754 | 0.2411 |
| 148 | 7 | 6 | 6 | 6.3333 | 0.0702 | 0.0911 |
| 152 | 7 | 6 | 6 | 6.3333 | 0.0702 | 0.0911 |
| 155 | 7 | 6 | 6 | 6.3333 | 0.0702 | 0.0911 |
| 160 | 6 | 7 | 6 | 6.3333 | 0.0702 | 0.0911 |
| 1 | 6 | 7 | 7 | 6.6667 | 0.0667 | 0.0866 |
| 27 | 7 | 7 | 6 | 6.6667 | 0.0667 | 0.0866 |
| 39 | 7 | 7 | 6 | 6.6667 | 0.0667 | 0.0866 |
| 57 | 7 | 7 | 6 | 6.6667 | 0.0667 | 0.0866 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 66 | 7 | 7 | 6 | 6.6667 | 0.0667 | 0.0866 |
| 9009 | 7 | 6 | 7 | 6.6667 | 0.0667 | 0.0866 |
| 9012 | 8 | 6 | 6 | 6.6667 | 0.1333 | 0.1732 |
| 90 | 7 | 7 | 6 | 6.6667 | 0.0667 | 0.0866 |
| 95 | 7 | 7 | 6 | 6.6667 | 0.0667 | 0.0866 |
| 104 | 9 | 6 | 5 | 6.6667 | 0.2333 | 0.3122 |
| 117 | 7 | 7 | 6 | 6.6667 | 0.0667 | 0.0866 |
| 122 | 7 | 7 | 6 | 6.6667 | 0.0667 | 0.0866 |
| 135 | 7 | 7 | 6 | 6.6667 | 0.0667 | 0.0866 |
| 162 | 8 | 6 | 6 | 6.6667 | 0.1333 | 0.1732 |
| 168 | 9 | 6 | 5 | 6.6667 | 0.2333 | 0.3122 |
| 6 | 6 | 8 | 7 | 7 | 0.0952 | 0.1428 |
| 29 | 6 | 8 | 7 | 7 | 0.0952 | 0.1428 |
| 56 | 7 | 7 | 7 | 7 | 0 | 0 |
| 77 | 7 | 8 | 6 | 7 | 0.0952 | 0.1428 |
| 9010 | 7 | 7 | 7 | 7 | 0 | 0 |
| 96 | 8 | 7 | 6 | 7 | 0.0952 | 0.1428 |
| 97 | 8 | 8 | 5 | 7 | 0.1905 | 0.2474 |
| 102 | 7 | 7 | 7 | 7 | 0 | 0 |
| 107 | 8 | 8 | 5 | 7 | 0.1905 | 0.2474 |
| 109 | 9 | 6 | 6 | 7 | 0.1905 | 0.2474 |
| 121 | 7 | 7 | 7 | 7 | 0 | 0 |
| 139 | 7 | 7 | 7 | 7 | 0 | 0 |
| 140 | 7 | 7 | 7 | 7 | 0 | 0 |
| 149 | 7 | 7 | 7 | 7 | 0 | 0 |
| 167 | 8 | 7 | 6 | 7 | 0.0952 | 0.1428 |
| 22 | 7 | 8 | 7 | 7.3333 | 0.0606 | 0.0787 |
| 33 | 7 | 8 | 7 | 7.3333 | 0.0606 | 0.0787 |
| 41 | 7 | 8 | 7 | 7.3333 | 0.0606 | 0.0787 |
| 48 | 9 | 7 | 6 | 7.3333 | 0.1515 | 0.2082 |
| 52 | 7 | 7 | 8 | 7.3333 | 0.0606 | 0.0787 |
| 9014 | 8 | 8 | 6 | 7.3333 | 0.1212 | 0.1574 |
| 9017 | 8 | 7 | 7 | 7.3333 | 0.0606 | 0.0787 |
| 88 | 8 | 8 | 6 | 7.3333 | 0.1212 | 0.1574 |
| 92 | 8 | 8 | 6 | 7.3333 | 0.1212 | 0.1574 |
| 101 | 8 | 7 | 7 | 7.3333 | 0.0606 | 0.0787 |
| 116 | 8 | 8 | 6 | 7.3333 | 0.1212 | 0.1574 |
| 120 | 8 | 8 | 6 | 7.3333 | 0.1212 | 0.1574 |
| 134 | 8 | 8 | 6 | 7.3333 | 0.1212 | 0.1574 |
| 150 | 9 | 5 | 8 | 7.3333 | 0.2121 | 0.2838 |
| 165 | 8 | 8 | 6 | 7.3333 | 0.1212 | 0.1574 |
| 24 | 7 | 9 | 7 | 7.6667 | 0.1159 | 0.1506 |
| 32 | 8 | 8 | 7 | 7.6667 | 0.0579 | 0.0753 |
| 35 | 7 | 9 | 7 | 7.6667 | 0.1159 | 0.1506 |
| 38 | 8 | 8 | 7 | 7.6667 | 0.0579 | 0.0753 |
| 55 | 7 | 9 | 7 | 7.6667 | 0.1159 | 0.1506 |
| 62 | 8 | 8 | 7 | 7.6667 | 0.0579 | 0.0753 |
| 70 | 8 | 8 | 7 | 7.6667 | 0.0579 | 0.0753 |
| 9008 | 8 | 7 | 8 | 7.6667 | 0.0579 | 0.0753 |
| 9011 | 9 | 7 | 7 | 7.6667 | 0.1159 | 0.1506 |
| 93 | 8 | 8 | 7 | 7.6667 | 0.0579 | 0.0753 |
| 115 | 8 | 8 | 7 | 7.6667 | 0.0579 | 0.0753 |
| 156 | 8 | 7 | 8 | 7.6667 | 0.0579 | 0.0753 |
| 166 | a | 7 | 8 | 7.6667 | 0.0579 | 0.0753 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 87 | 9 | 8 | 7 | 8 | 0.0833 | 0.125 |
| 89 | 9 | 8 | 7 | 8 | 0.0833 | 0.125 |
| 157 | 9 | 7 | 8 | 8 | 0.0833 | 0.125 |
| 141 | 8 | 8 | 9 | 8.3333 | 0.0533 | 0.0692 |
| 72 | 9 | 9 | 8 | 8.6667 | 0.0512 | 0.0666 |
| 72 | 8 | 10 | 8 | 8.6667 | 0.1025 | 0.1332 |
| 9018 | 10 | 8 | 8 | 8.6667 | 0.1025 | 0.1332 |
| 136 | 9 | 9 | 8 | 8.6667 | 0.0512 | 0.0666 |
| 54 | 9 | 9 | 9 | 9 | 0 | 0 |
| 63 | 9 | 10 | 8 | 9 | 0.0740 | 0.1111 |
| 143 | 9 | 10 | a | 9 | 0.0740 | 0.1111 |
| 161 | 10 | 9 | a | 9 | 0.0740 | 0.1111 |
| 138 | 10 | 10 | 9 | 9.6667 | 0.0459 | 0.0597 |
| 142 | 10 | 10 | 9 | 9.6667 | 0.0459 | 0.0597 |
| 170 | 10 | 10 | 9 | 9.6667 | 0.0459 | 0.0597 |
| 45 | 10 | 11 | 9 | 10 | 0.0666 | 0.1 |
| 9001 | 10 | 10 | 10 | 10 | 0 | 0 |
| 9006 | 9 | 11 | 10 | 10 | 0.0666 | 0.1 |
| 9013 | 10 | 10 | 10 | 10 | 0 | 0 |
| 9021 | 11 | 10 | 9 | 10 | 0.0666 | 0.1 |
| 86 | 11 | 11 | 8 | 10 | 0.1333 | 0.1732 |
| 9005 | 11 | 10 | 10 | 10.3333 | 0.0430 | 0.0558 |
| 9007 | 10 | 10 | 11 | 10.3333 | 0.0430 | 0.0558 |
| 110 | 11 | 10 | 10 | 10.3333 | 0.0430 | 0.0558 |
| 53 | 11 | 11 | 10 | 10.6667 | 0.0416 | 0.0541 |
| 42 | 11 | 12 | 10 | 11 | 0.0606 | 0.0909 |
| 60 | 10 | 11 | 12 | 11 | 0.0606 | 0.0909 |
| 83 | 11 | 11 | 11 | 11 | 0 | 0 |
| 9002 | 11 | 11 | 11 | 11 | 0 | 0 |
| 9004 | 11 | 11 | 11 | 11 | 0 | 0 |
| 100 | 11 | 11 | 11 | 11 | 0 | 0 |
| 158 | 11 | 11 | 11 | 11 | 0 | 0 |
| 46 | 11 | 12 | 11 | 11.3333 | 0.0392 | 0.0509 |
| 9015 | 12 | 12 | 10 | 11.3333 | 0.0784 | 0.1018 |
| 118 | 12 | 12 | 10 | 11.3333 | 0.0784 | 0.1018 |
| 133 | 12 | 12 | 10 | 11.3333 | 0.0784 | 0.1018 |
| 9016 | 12 | 10 | 13 | 11.6667 | 0.0952 | 0.1309 |
| 154 | 12 | 12 | 11 | 11.6667 | 0.0380 | 0.0494 |
| 37 | 13 | 13 | 10 | 12 | 0.1111 | 0.1443 |
| 164 | 13 | 13 | 10 | 12 | 0.1111 | 0.1443 |
| 9003 | 13 | 13 | 12 | 12.6667 | 0.0350 | 0.0455 |
| 9020 | 12 | 12 | 14 | 12.6667 | 0.0701 | 0.0911 |
| 58 | 16 | 11 | 12 | 13 | 0.1538 | 0.2035 |
| 61 | 14 | 12 | 13 | 13 | 0.0512 | 0.0769 |
| 112 | 13 | 13 | 13 | 13 | 0 | 0 |
| 113 | 13 | 13 | 13 | 13 | 0 | 0 |
| 47 | 13 | 15 | 13 | 13.6667 | 0.0650 | 0.0844 |
| 65 | 14 | 14 | 13 | 13.6667 | 0.0325 | 0.0422 |
| 119 | 14 | 13 | 15 | 14 | 0.0476 | 0.0714 |
| 108 | 15 | 13 | 15 | 14.3333 | 0.0620 | 0.0805 |
| 68 | 16 | 16 | 14 | 15.3333 | 0.0579 | 0.0753 |
| Total | | 153 | | 7.97821 | 0.0737 | 0.0992 |

**REPORTB**

Feasibility of Commercial and Bounty Fisheries for Northern Squawfish

Prepared by:

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CONTENTS

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We thank Steven Vigg of the Oregon Department of Fish and Wildlife (ODFW) for valuable suggestions related to market development and for his efforts in providing coordination between this project and the Harvest Technology project. We thank Steven Vigg and Craig Burley, ODFW, for their extra efforts in providing fish for market tests. Hoa van Huynh, Graduate Research Assistant at Oregon State University, did excellent work making and sustaining business contacts in the Asian community. Members of the Harvest Technology Project helped by delivering fish and were cooperative in providing data. We thank Gene Foster, Oregon Department of Environmental Quality, Water Quality Division, for his cooperation with this project and his help in overseeing the conduct of the contaminant analyses.

Thanks are also due to the owners of restaurants and markets who cooperated with us during the test marketing period: Mr. Phong, A Dong Market, Salem; Mr. Pham, 99 Market, Portland; Mrs. Nguyen, Quyen's Market, Beaverton; Mr. Tri, Golden Asia Supermarket, Portland; Mrs. Hue, Phong Phu Market, Portland; Mrs. Lane, Seven Stars Restaurant, Portland; Mr. Wong, Tuck Lung Restaurant, Portland; Mr. Ford, Henry Ford's Restaurant, Portland; and Mrs. Thai, Yen Ha Restaurant, Beaverton. We thank Roy Gilmore, fish buyer of Dallesport, WA and Jim Bahrenberg, Inland Pacific Fisheries, Ontario, OR, for their cooperation. We thank Neil Grasstiet, Grasstiet Fish Company, Fallon, NV, for generously sharing market information. Susume Kato, National Marine Fisheries Service, Tiburon, CA also generously provided information which helped to understand critical market factors.

## ABSTRACT

We report on our research conduct from February 1989 through May 1990 on the analysis of feasibility of commercial and bounty fisheries for northern squawfish (Ptychocheilus oregonensis). Northern squawfish were provided to this project by the Predation Project of Vigg and Burley (this volume) and by the Harvest Technology Project of Mathews (this volume). Samples of northern squawfish were provided to the Oregon Department of Environmental Quality for contaminant testing. Contaminant levels tested so far indicate levels below FDA Action Levels.

We made contacts with several fish vendors and processors to outline a range of alternative end uses for northern squawfish. These included restaurants, retail markets, bait, multiple-use processing, fish meal, and animal feed. Northern squawfish were available for utilization testing from June 22, 1989 until August 10, 1989. During this time we tested three end uses: restaurants, markets, and bait. The restaurant and market trials were conducted with Asian businesses in the Portland area and in Salem. Results of these trials indicate that although the flavor and texture of northern squawfish was highly rated, boniness was a problem. Plans to introduce a minced, de-boned product form to the market for testing were inhibited by a lack of supply of fresh squawfish in Fall 1989. Frozen fish accumulated during the 1989 fishing season were delivered during Fall 1989 to Inland Pacific Fisheries, Ontario, OR, for trial in a multiple-use processing line.

An investigation into alternate market names was begun. A small number of carp (Cyprinus carpio) and suckers (Catostomus spp.) were test marketed with squawfish. The analysis of regulatory constraints to fishery development was begun and continued throughout the year.

# INTRODUCTION

We began our research of the feasibility of alternative fisheries for northern squawfish (Ptychocheilus oregonensis) on 1 February 1989. This report summarizes our research activities and results during the first year of the project, until 31 May 1990. Our objective was to begin the evaluation of the economic feasibility of commercial and bounty fisheries on northern squawfish, and to assist the Oregon Department of Fish and Wildlife (ODFW) in an evaluation of recreational fishery feasibility. This involved:

1. Testing various end uses for northern squawfish.

2. Assessing costs and returns of various end uses for northern squawfish.

3. Collecting data on transportation costs.

4. Assessing regulatory constraints.

Figure B-1 outlines these and other research tasks which comprise the Feasibility Project.

# METHODS

## Sampling

This project involved sampling at both harvest and market sites. The harvest site was the John Day Reservoir of the Columbia River. Populations of northern squawfish were sampled in accordance with research objectives of two projects: the Harvest Technology Project of Mathews et al. (1990) and the parent Predation Project of Vigg and Burley (1990).

Northern squawfish were sampled by both the Predation Project and the Harvest Technology project during an eight week period June 22-August 10, 1989. Samples were provided to the Feasibility Project during this time period. Northern squawfish were caught using hook and line, gillnets, and long lines at several locations in the John Day Reservoir, as described in Mathews et al (1990). Fish size ranged from < 1 lb. to >3 lbs. Samples averaged 236 lbs. Small samples of suckers and carp were also provided to the feasibility project for market tests.

We sampled potential food market sites in Oregon urban areas. Because prior marketing information indicated that primary markets would be found in Asian communities, we limited our sampling efforts to the Portland and Salem areas, where Oregon's largest concentrations of Asians live. We visited Asian markets and restaurants in these areas to explain the research aims of the project and offer northern squawfish

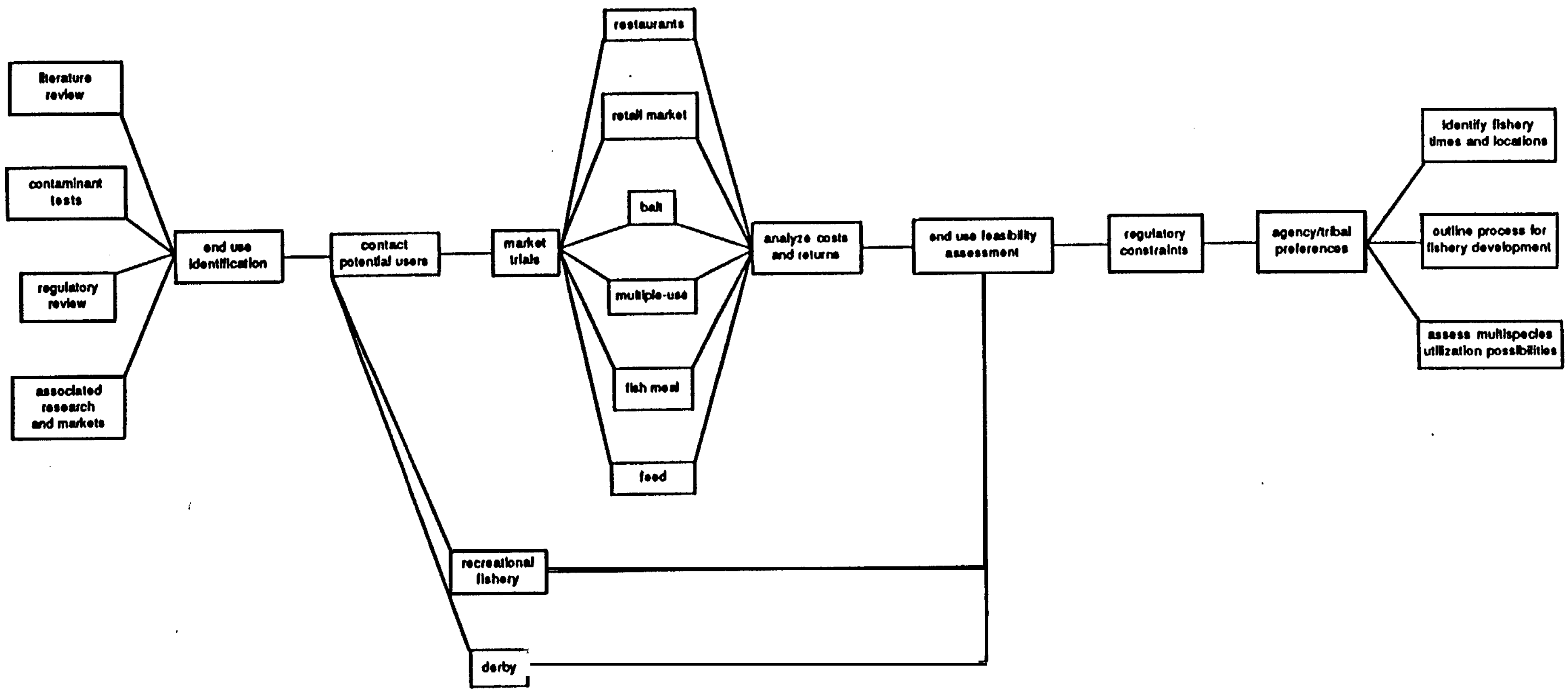



Figure B-1. Research Tasks of Project "Feasibility of Commercial and Bounty Fisheries for Northern Squawfish."

deliveries to those markets and restaurants interested in using northern squawfish in their businesses. We contacted businesses of different sizes and with different customer groups to get as representative a sample of businesses as possible.

We requested that businesses receiving deliveries of northern squawfish provide us with information on handling costs, selling price, customer response and any other relevant marketing factors. Each business filled out a data form for each delivery. We conducted follow-up interviews with each participating business at the end of the summer delivery period. Constraints on the quantity of northern squawfish available limited the number of project participants to seven at any one time. A total of nine markets and restaurants cooperated with us over the entire sampling period. These businesses were located in Portland, Beaverton, and Salem.

Other market sites were chosen on the basis of the location of processor facilities for other identified end uses. Northern squawfish were provided to a fish buyer in Dallesport, WA. to be sold as crayfish bait. An agreement was reached with Bioproducts, Inc. in Warrenton, OR, to provide surplus fish from the summer's fishery for fish meal processing. We agreed to provide frozen fish accumulated throughout the fishery to Inland Pacific Fisheries, Ontario, OR, for trial in a multiple-use processing line.

## Contaminant Tests

Before supplying northern squawfish for use as a food fish we wanted to ensure that contaminant levels were low enough for human consumption. We arranged with the Oregon Department of Environmental Quality (DEQ) to include northern squawfish in fish tissue tests run in May. We delivered twelve fish of different ages to the DEQ's Division of Water Quality Planning. We requested that the DEQ test both northern squawfish and carp fillets and organs for pesticides (PCB's, chlordane, DDT derivatives) and heavy metals (mercury, aluminum, lead, arsenic). The DEQ does not have testing capability for either dioxins or radioactivity.

## End Uses

After preliminary discussions with people knowledgeable about northern squawfish and species with characteristics similar to northern squawfish, we decided to test northern squawfish in several end uses: restaurants, markets, bait, multiple use processing, processed fish feed and animal food. We contacted people involved with each type of use, offering free deliveries of northern squawfish for trial in exchange for data on costs and returns in each use.

Restaurants: Sacramento blackfish (Orthodon microlepidotus), a species similar to northern squawfish, has been marketed in Chinese restaurants in the San Francisco area (Kato 1987). Discussions with several people with experience in the San Francisco market indicated that the food fish market for northern squawfish would likely be an Asian ethnic market. Northern squawfish is a bony fish; Asian consumers have a relatively high tolerance for bones as well as a preference for freshwater fish. Contacts were made with several Asian restaurants in the greater Portland and Salem areas to assess interest in testing northern squawfish. We agreed to provide weekly deliveries of northern squawfish during the eight week sampling period in exchange for information on handling costs, sales price, and marketing problems.

Markets: For the reasons stated above, likely market sources for northern squawfish sales were determined to be Asian markets. Several Portland and Salem markets of various sizes were contacted. We agreed to provide weekly deliveries of northern squawfish to these markets in exchange for information on handing costs, sales price, and marketing problems.

Out-of-State Restaurants and Markets: We also talked with a fish buyer, a fish broker, and a fish marketer about shipping northern squawfish to California for testing in the San Francisco market.

Bait: We provided a 300 lb. delivery of frozen northern squawfish to a Columbia River fish buyer for testing as bait by crayfish fishermen.

Multiple-Use Processing: An agreement was made with Inland Pacific Fisheries, Inc., a multiple-use carp processing facility, to test northern squawfish. This production process uses fish flesh, skin, and glands. Throughout the sampling period, surplus northern squawfish were frozen and stored at the Irrigon Fish Hatchery for this use.

Fish Meal: We arranged with Bioproducts, Inc. in Warrenton, OR to sell them any surplus northern squawfish for processing into fish meal.

Animal Feed: We received a request from the Army Corps of Engineers to provide surplus northern squawfish to their bald eagle feeding program.

## Transportation

The gear technology project provided transportation of fish to the Portland area in eight weekly trips. Northern squawfish were transported in both live and iced forms. Live fish were held at different densities. Data were collected on various handling and transportation costs associated with each trip.

## Regulation

We reviewed the statutory restrictions concerning the use of northern squawfish, designated as a "food fish" (Oregon Wildlife and Commercial Fishing Codes 1987-1988). A description of information needed to complete an Environmental Assessment (EA) and an Environmental Impact Statement (EIS) for fishery development was provided to us by the Coordination and Review Division of the Bonneville Power Administration (BPA). Meetings were held with ODFW personnel throughout Fall 1990 to outline preliminary regulatory concerns related to the prosecution of a fishery on northern squawfish. A "straw man" fishery implementation plan was developed and reviewed within the Oregon Department of Fish and Wildlife. The purpose of the fishery implementation plan is to determine the regulatory concerns of each agency related to the various end uses of northern squawfish and the potential development of a northern squawfish fishery. The fishery implementation plan will be revised until it receives final approval (Figure B-2).

## Market Name

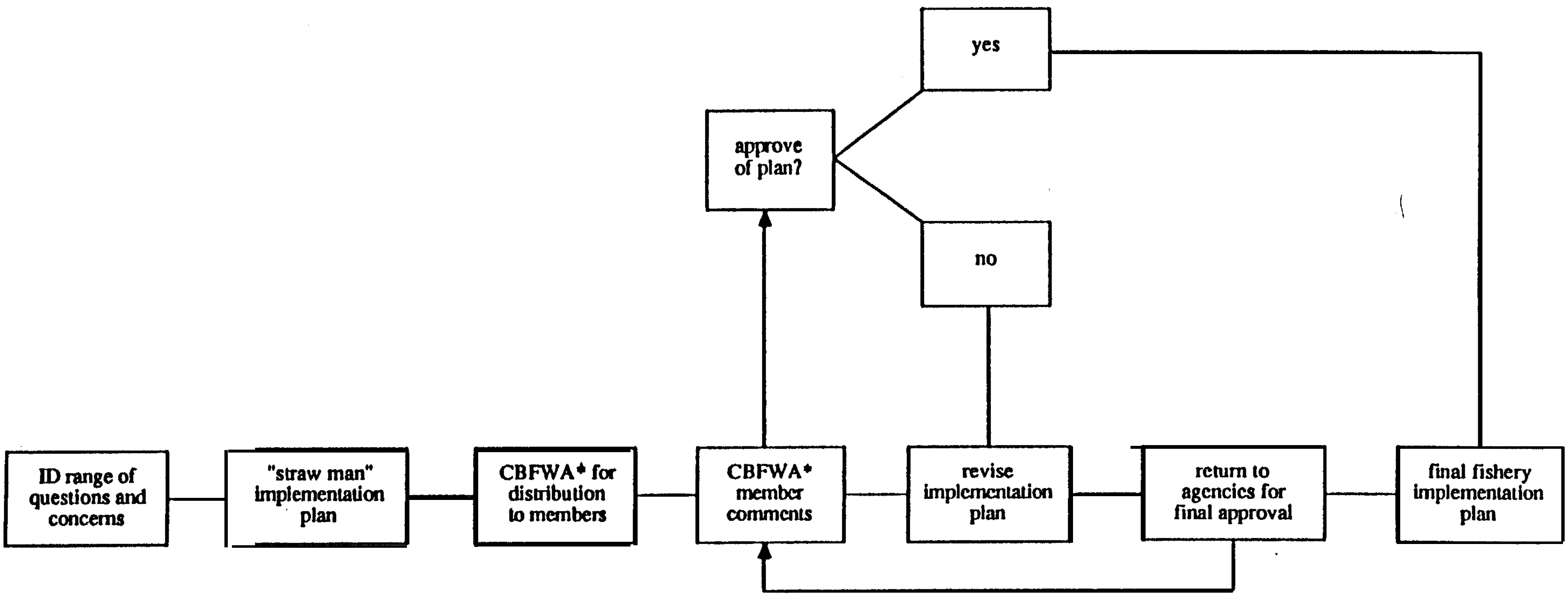
Recognizing that the "northern squawfish" name might inhibit market development efforts, we initiated research into an alternative name more appropriate for marketing. We contacted the U.S. Food and Drug Administration to determine the protocol for assigning market names to fish. We also made contacts with tribal representatives as well as researchers who might know of alternative names used by tribal fishermen.

## Associated Species

In recognition of the possible multispecies nature of a northern squawfish fishery, we included carp (Cyprinus carpio) and suckers (Catostomus spp.) in various feasibility considerations. We requested samples of incidentally-caught carp and suckers from the Harvest Technology project. We were able to provide small numbers of suckers and one carp to restaurants and markets during the summer sampling period.

## Associated Research

A research project supported by Saltonstall-Kennedy funds was investigating harvesting techniques and marketing possibilities for Sacramento squawfish (Ptychocheilus grandis) from Red Bluff Dam, CA (Laveen 1988). We contacted the Technical Monitor for this project, Susume Kato at the Tiburon, CA, Lab, National Marine Fisheries Service, to share information on our project and to avoid duplication of effort.




* Columbia Basin Fish and Wildlife Authority

Figure B-2. Development of a Prototype Fishery Implementation Plan for Northern Squawfish

# RESULTS

## Contaminant Tests

Results of tests for organic contaminants are summarized in Appendix B-2.2. All organic contaminant levels are below FDA foodstuff action levels. FDA foodstuff action levels are enumerated in Table B-5, Appendix B-2.1. Tests for heavy metals contamination are summarized in Appendix B-2.3. Mercury, the only heavy metal for which an FDA action level exists, tests at below-action level. Both organic and inorganic contaminant testing results indicate that northern squawfish is suitable for human consumption. Tests for dioxin accumulation are planned for the 1990 fishing season.

## End Uses

Restaurants: A total of five Vietnamese, Chinese and American restaurants in Portland and Beaverton accepted northern squawfish for trials. Three restaurants terminated test marketing after the initial sample; the remaining two continued throughout the summer sampling period. Tables B-1 and B-2 summarize the restaurant and market deliveries during the test market period. All restaurants reported that the fish were easy to handle and prepare, and all evaluated the flesh as good quality. Preparation was by steaming, frying, or sauteing. Dishes made with northern squawfish were priced between $5.60 and $7.50. Problems were reported with bones; some customers were reluctant to take the extra time required by the bones, others did not want a bony fish served to children (Table B-3).

Markets: Five Vietnamese markets of various sizes in Portland, Beaverton and Salem received samples of northern squawfish and suckers. Two markets terminated tests after the first delivery; the three remaining markets took multiple deliveries. The northern squawfish sold with varying degrees of success. The fish was priced between 29 cents and 99 cents per lb. All markets found the fish easy to prepare and were satisfied with the quality of the flesh. Market problems related to the unfamiliarity of the fish to consumers, the boniness of the fish, and the summer season when many Vietnamese are catching food fish recreationally rather than purchasing it.

Two main marketing problems were identified by both restaurants and markets: 1) the unfamiliarity of northern squawfish; and 2) the large number of small bones in northern squawfish. Owners reported good consumer acceptance of the taste and texture of northern squawfish flesh. Fifty percent of the restaurants and markets in the summer sample were willing to test market the northern squawfish again in 1990 if a test fishery continued. During exit interviews conducted at the end of the 1989 deliveries, sixty-three percent of the sample markets and restaurants indicated an interest in trying the deboned fish product and felt that it would sell well.

Table B-1. Restaurants and Markets Receiving Squawfish Deliveries, June 22 - August 10, 1989.

| | Delivery Date | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6/22/89 | 6/29/89 | 7/6/89 | 7/13/89 | 7/20/89 | 7/27/89 | 8/3/89 | 8/10/89 |
| **Business** | | | | | | | | |
| A Dong Market Salem | X | X | X | X | X | | X | |
| 99 Market Portland | | | | | | X | X | X |
| Quyen's Market Beaverton | X | | | | | | | |
| Golden Asia Supermarket Portland | X | X | X | X | X | | | |
| Phong Phu Market Portland | | | | | X | | | |
| Seven Stars Restaurant Portland | X | | | | | | | |
| Tuck Lung Restaurant Portland | X | | | | | | | |
| Henry Ford's Restaurant Portland | X | | | | | | | |
| Yen Ha Restaurant Beaverton | X | X | X | X | X | X | X | X |

Table B-2. Form, Number, and Weight of Fish Delivered to Restaurants and Markets, June 22 - August 10, 1989.

| | Delivery Date | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6/22/89 | 6/29/89 | 7/6/89 | 7/13/89 | 7/20/89 | 7/27/89 | 8/3/89 | 8/10/89 |
| No. Deliveries | | | | | | | | |
| iced | --- | 3 | 3 | --- | 4 | --- | 3 | 2 |
| live | 6 | --- | --- | 3 | --- | 4 | --- | --- |
| No. Fish Delivered | 99 | 63 | 99 | 105 | 104 | 135 | 117 | 60 |
| Wt. Fish Delivered (lbs.) | 250 | 187 | 228 | 270 | 260 | 338 | 303 | 150 |

Table B-3. Summary of Restaurant and Retail Market Evaluation of Squawfish, June 22 - August 10, 1989.

| | |
|---|---|
| Preferred Size | < 2 lbs. |
| Preferred Form | head on, gutted |
| Ease of Handling | good |
| Average Selling Price | |
| restaurant dish | $6.55 |
| retail market | $.76 per lb. |
| Preparation | steamed, fried, stewed |
| Taste | good |
| Texture | flakey |
| Customer Response | hesitant to somewhat positive |
| Marketing Problems | bones<br>fish available recreationally |
| Alternate Product Form | deboned, minced |

In light of the problem with bones, we decided to try test marketing a de-boned fish product to be used in fish cakes and fish balls. We contacted the Astoria Seafood Lab about running a sample of northern squawfish through a deboning machine. Plans were made to deliver northern squawfish to Astoria for deboning. However, at the resumption of sampling activity in Fall 1989 it was discovered that catching squawfish became very difficult with the decrease in water temperature. Catch rates during Fall 1989 were too low to accumulate enough fresh fish (approximately 300 lbs.) to perform the deboning tests. As a result the deboning experiment was delayed until the 1990 fishing season.

California Restaurants and Markets: Initial plans to ship northern squawfish to the San Francisco market were canceled when both the buyer and broker reported soft markets for northern squawfish. The reported price per pound for Sacramento squawfish this summer was $.50, a price too low to cover transportation and marketing costs (N. Grasstiet, Personal Communication).

We did not pursue further efforts to ship northern squawfish to California. We did maintain communication with the Washington fish broker and the California fish wholesaler to keep apprised of any changes in the San Francisco market that would indicate better market possibilities for northern squawfish.

Bait: Frozen northern squawfish was used successfully for crayfish bait. The fish buyer who provided fishermen with the bait estimated a selling price of 10 cents per pound. Northern squawfish were readily accepted for use as crayfish bait. The feasibility of using northern squawfish for bait relative to other uses will be assessed when data on all uses is complete.

Multiple-Use Processing: Frozen northern squawfish from the summer sampling period are being stored at the Irrigon Fish Hatchery for provision to the multiple-use processor. A sample of 100 lbs. of frozen northern squawfish was transferred to Inland Pacific Fisheries for initial testing. This sample was followed in late Fall 1989 by a delivery of frozen northern squawfish accumulated during the 1989 fishing season. Experiments were run on 2,000 lbs. of northern squawfish. One experiment was conducted; northern squawfish used in an enzyme hydrolysate process to produce a liquid base for organic fertilizer. The liquid product uses the whole fish in processing. The company was satisfied with the results of the liquid hydrolysate test and requested further deliveries of northern squawfish in 1990.

Fish Meal and Animal Feed: Due to the poor fishing success during the Fall 1989 sampling period, surplus northern squawfish were not available for these two purposes.

Plans to collect cost and return data on tests of northern squawfish in multiple-use processing, fish meal processing, and animal feed were delayed until the 1990 test fishery. Full information on the costs and returns of the full range of end uses will be used to evaluate the relative economic feasibility of each use.

## Transportation

Both live and iced fish transported well to the market. Live fish transported in tanks were vigorous upon delivery in Portland. Live fish iced in Umatilla were still alive on delivery to Portland, five hours later. The biggest quality problem occurred with northern squawfish that had been dead a day by the time of delivery. The skin of these fish became mottled in color. The mottling was primarily a cosmetic problem; flesh quality was not affected. The components of transportation costs are summarized in Table B-4.

## Regulation

The first regulatory review meeting was held with ODFW personnel in September 1989. Issues related to the development of a 1990 test fishery on northern squawfish were discussed. These issues included the necessary components of a review process before initiation of a test fishery, the timing of the planning process, and the identification of fishery participants. Further meetings were held in October 1989 to plan for agency input into the test fishery plan. Following these meetings, a preliminary "straw man" fishery implementation plan was developed and circulated with the Oregon Department of Fish and Wildlife for review comments.

Reviews of the first fishery implementation Plan indicated an inadequacy in the Plan to cover all contingencies which might arise under different fishery development arrangements. As a result, another project meeting was held in February 1990 to identify a full range of fishery development issues and to specify a workable approach to acquiring the necessary information. On the basis of issues identified during this planning session, the Fishery Implementation Plan was rewritten in questionnaire form with questions addressed to issues related to the development of each type of fishery. The questionnaire was then reviewed by Oregon Department of Fish and Wildlife personnel in preparation for mailing to all agencies with Columbia River fishery jurisdiction for their reaction and revision (Figure B-2).

## Market Name

The test marketing of northern squawfish in Asian restaurants and markets provided mixed results on the need to provide a market name for northern squawfish. One market owner felt very strongly that the name should be changed. Others felt indifferent about the name. Efforts were made during Fall 1990 to pursue literature which would identify an historical name used for northern squawfish that might serve as a market name. No historical literature was identified which provided an alternate name. A brief memo was distributed in February 1990 to members of the Columbia Basin Fish and Wildlife Authority asking for any information on alternative names for northern squawfish. A single response resulted from this request. A list of Nez Perce

Table B-4. Cost Components of Squawfish Deliveries to Portland, Sampling Period 6/22/89 - 8/10/89.

| | |
|---|---|
| Total Number of Deliveries | 8 |
| Delivery Vehicle Types | 1) 1 ton flatbed truck<br>2) 1/2 ton pickup truck<br>3) Toyota truck |
| Average Number of People Delivering | |
| To Portland | 1.25 |
| Around Portland | 2.13 |
| To Salem | 1.00 |
| Average Trip Mileage (Umatilla-Portland round trip) | 398 miles |
| Average Delivery Time | 9.1 hrs. |
| Average Number of Fish Delivered | 98 |
| Average Weight of Fish Delivered (estimated) | 244 lbs. |
| Average Fuel Use per Trip | 33.9 gal. |
| Average Fuel Cost per Trip | $40.74 |
| Average Ice Cost per Trip Used | $13.76 |
| Average Oxygen Cost per Trip Used | $19.00 |
| Delivery Equipment Purchase Cost | |
| Ice Chests | $84.00 |
| Holding Tank | $272.00 |
| Garbage Cans (carrying tanks) | $72.00 |

words for various species of fish - including squawfish - was received from the Nez Perce Tribe Department of Fisheries Management. Attempts to identify other names for northern squawfish have so far been unsuccessful.

## Associated Species

A small number of suckers and one carp were provided to markets and restaurants during the test marketing period. The carp sold well with no reported problems. The suckers also sold in one market, but less well. The main marketing problem reported for suckers was the small ratio of flesh to head and bones. It is likely that marketing efforts for carp and suckers will face the same need identified for northern squawfish; that of time in the market to increase consumer familiarity with the species.

## Associated Research

The Sacramento River Squawfish Project funded by Saltonstall-Kennedy was designed to experiment with fish traps placed in the vicinity of fish ladders and to sell live fish in the San Francisco market. The harvest technology portion of the Red Bluff Dam project proceeded under a modified research plan due to two factors: 1) repair work in the fish ladder area of the Red Bluff Dam resulted in few squawfish traversing the fish ladder; 2) a prohibition by the California Department of Fish and Game of marketing of Sacramento squawfish for human consumption due to dioxin levels measured in the flesh of Sacramento squawfish.

Due to the ban on the use of Sacramento squawfish for human consumption, the harvested fish could not be sold in the San Francisco market as planned. Plans to use Sacramento squawfish as bait in the hagfish fishery did not materialize. No utilization trials for Sacramento squawfish were conducted during this study. (S. Kato, Personal Communication).

Although fish traps were not tested in the fish ladder area due to construction activities, this gear was tested in other locations along the Sacramento River and some of its tributaries. Several sizes and shapes of fish traps were tried; the most successful traps were a rectangular trap (78" x 40" x 30" high) and a cylindrical trap (48" long by 20' diameter). Hook and line gear used at the Red Bluff Diversion Dam was the most successful gear type used for Sacramento squawfish. The gear type which was the original focus of this research - fish trap gear used on fish ladders - still remains to be tested (Laveen 1990).

Conventional fish traps using fish parts, fish oil, and trout pellets as bait were unsuccessful in catching Sacramento squawfish but were very effective in the capture of hardhead (Mylopharodon conocephalus), also thought to be a predator of juvenile salmon. This catching method resulted in very low incidental catch of other species (Laveen 1990).

## DISCUSSION

### Contaminant Tests

Based on tests performed to date, contaminant levels in northern squawfish appear to be low enough to market northern squawfish as food fish. Unless the dioxin tests indicate a problem, we will continue to pursue food uses for northern squawfish. A budget for dioxin tests will be included in the 1990 Test Fishery budget. Dioxin tests will be contracted through the Oregon Department of Environmental Quality Water Quality Division.

### End Uses

Due to a limited quantity of northern squawfish available for experimentation during the 1989 fishing season, we were unable to try all the end uses identified in the Statement of Work. For the same reason we were unable to collect full cost and return information of the alternate fishery uses with which to compare cost effectiveness of each end use. The trials we conducted do, however, allow us to make some preliminary qualitative assessments of the feasibility of various end uses.

Restaurants and Markets: Based on consumer tests of northern squawfish in Asian restaurants and markets from June to August, it appears that northern squawfish have good marketing potential in these areas only with a modification of product form. To gain consumer acceptance the fish should be kept in the market for longer periods of time and should be marketed in an alternative form. We feel that deboned minced fish has the greatest potential for sustained market acceptance in both restaurants and retail stores.

Bait: The use of northern squawfish as bait is acceptable but is a low-valued use. We will collect further data on the likely quantity demanded for this use; our prior expectation is that the bait market would absorb relatively small quantities of northern squawfish. The fish buyer has indicated an interest in selling squawfish for bait in fisheries other than crayfish. Some of the 1990 fishery catch will be used in this manner.

Multiple-Use Processing, Fish Meal, and Animal Feed: In addition to its use of northern squawfish in the production of a liquid base for organic fertilizer, Inland Pacific Fisheries also indicated an interest in experimenting with northern squawfish fillets to be minced and frozen for food fish. We agreed to continue deliveries of northern squawfish to this company during the 1990 fishing season.

Further experiments on these uses will have to wait until the 1990 fishing season. Once total catch weight is high enough we will deliver northern squawfish to these processors to determine how the alternatives of multiple-use, fish meal, and animal feed compare to the use of northern squawfish as food. Larger volumes processed will also allow us to collect data on processing costs for full production volumes rather than small samples. It appears that northern squawfish have a potential large-volume use in the processing of liquid fertilizer base, although the economics of this operation are not yet known.

## Transportation

Transportation of northern squawfish to market was not a particular problem. Northern squawfish are hardy and were able to resist stresses of moving when handled properly. The mottling of northern squawfish skin within one day after death presents some cosmetic difficulties to marketing. Suckers and carp also transported well. Costs incurred by the transportation of live fish to market suggest that going to the extra efforts to transport live - rather than fresh iced - fish to market will not be cost-effective. Retail selling price was not sensitive to live as compared to dead-iced fish form.

## Regulation

Regulations pertaining to "food fish" prevent "wanton disposal" of northern squawfish and require utilization once harvested (Oregon Wildlife and Commercial Fishing Codes 1987-1988). Further regulatory concerns expressed by ODFW personnel include incidental catch of game species, impacts on wildlife food sources, and harvest rights. Responses to the "Regulatory Review" questionnaire mailed to various regulatory entities are likely to identify additional regulatory concerns regarding the development of a fishery on northern squawfish.

## Market Name

The name "northern squawfish" does not appear to be a particular hindrance to marketing in the Asian market, but could be a problem if utilization occurs outside the Asian community. We will continue to pursue the identification or development of alternative market names to propose to the Food and Drug Administration.

## Associated Species

We requested that carp and sucker be included in northern squawfish deliveries received from the Harvest Technology project during their Fall 1989 fishing period. These fish were to be included in as many of the northern squawfish utilization tests as possible. For reasons identified above, limited quantities precluded all further trials during Fall 1989.

## Associated Research

We maintained contact with the Sacramento squawfish research being conducted at Red Bluff Dam, CA. The final report of that project was submitted in May 1990 (Laveen 1990). Information on alternative utilization methods of harvested Sacramento squawfish from that project is not forthcoming from this project. However, personal communication with the project's Technical Monitor indicated that future research on the Eel River may include some marketing of squawfish in the San Francisco food market if contaminant levels are low.

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# APPENDIX B-l.

## Annotated Bibliography on the Feasibility of Commercial, Sport and Bounty Fisheries

Prepared by

Susan Hanna, Steven Vigg, and Hoa van Huynh

**APPENDIX B-l.**
**Annotated Bibliography of Literature on Commercial, Sport and Bounty Fisheries**

Adams, G.F. 1978. An historical review of the commercial fisheries of the boreal lakes of central Canada: their development, management, and potential. Pages 347-360 in Selected coolwater fishes of North America, R.L. Kendall, ed., American Fisheries Society Special Publication No. 11.

Abstract: A chronology of the development and subsequent decline of commercial fisheries (whitefish, walleye and sturgeon) on the boreal lakes of central Canada is presented. Historically, development of the remote northern fisheries was based on welfare objectives rather than economics; presently government agencies have responded to declining conditions by providing subsidy and incentive programs that have the potential to further stress the fish stocks. Quota control of harvest was a positive action toward prevention of overutilization by the commercial fishery, but measures were not taken to prevent overinvestment in the industry and the decrease in profits to fishermen. From a strict economic perspective, the fishery resources of this region are being mismanaged under a policy that does not result in a positive net return in harvested fish to either the fishing industry or the public. If a policy of managing the fisheries as common property is continued, there will be a pervasive tendency for the cost of production to exceed the value of production.

The management implication of this case study is that effective fisheries programs require: 1) a recognition and respect for the value of fisheries resources; 2) a real effort by fisheries institutions to eliminate the fragmented approach to management; 3) an acceptance and implementation of the experimental "adaptive management" approach, and 4) an immediate transfer of insights and information directly to planning and policy-making.

Although the fishery discussed in this paper is quite different from the proposed fishery on northern squawfish, some of the management implications of this case study are important. In recognition of the potential value of a commercial squawfish fishery on the Columbia River, development should proceed on a sound economic basis rather than by dependence on government subsidies. A controlled-harvest limited entry fishery could be managed to prevent problems which commonly occur in open access fisheries. Coordinated planning and development is important for effective management of the fishery resource. Harvest strategies should be based on indices that incorporate broad ecological relationships and fish community structure. This point is especially relevant since the resident fish community structure will likely be modified in order to manage for anadromous salmon species. Harvest strategies designed as adaptive management experiments would be compatible with the NPPC philosophy of adaptive management. Adaptive management has important implications for the development of a fishery within the context of a plan which evaluates the efficacy of control fisheries as they proceed.

**Keywords:** fisheries development, economics, open access, limited access, adaptive management, agency coordination.

American Fisheries Society. 1982. Monetary values of freshwater fish and fish-kill counting guidelines. American Fisheries Society Special Publication No. 13.

**Abstract:** This paper was prepared by the Monetary Values of Fish Committee of the American Fisheries Society and by the Pollution Committee of the Southern Division of the American Fisheries Society. The manuscript contains a set of monetary values of freshwater fish that may be used, in conjunction with standard sampling programs, to assess the value of fish destroyed in fish kills, in fishery mitigation efforts, in the preparation of environmental impact statements, and in the evaluation of competing water uses. The monetary values concept is based on three premises: 1) fish are resources with tangible value to the public and to the aquatic ecosystem; 2) when fish are destroyed and blame can be assigned compensation to the public agency responsible for management is required; 3) hatchery production costs provide the most reasonable source of fish value information. Values are assigned to various fresh water game, nongame, and commercial species on both a per-pound and per-fish basis. There is explicit recognition of the fact that damages from fish kills are greater than just the monetary value of the lost fish and extend to costs of investigation and clean up.

Although several Cyprinids are listed, squawfish is not one of the species assigned a monetary value in this report. However, if development of a fishery on squawfish proceeds, valuation techniques such as those outlined here will be useful for fishery impact assessment and valuation. This manuscript will soon be reissued with updated values.

**Keywords:** freshwater fish, values, fish kills, mitigation, assessment.

Anderson, L., A. Ben-Israel, G. Custis, and C. Sarabun. 1981. Modeling and simulation of interdependent fisheries, and optimal effort application using mathematical programming. In Applied Operations Research in Fishing, K.B. Haley, ed., Vol. 10, NATO Conference Series. New York: Plenum Press.

**Abstract:** In this paper both simulation and mathematical programming techniques are discussed as approaches to the analysis of fisheries management policies. Simulation modeling provides the best tool at present for evaluating alternative management policies in fisheries with complex interactions. Mathematical programming can be used under more simplified assumptions to determine optimal harvest levels and optimal effort allocation in fisheries, subject to relevant constraints. Fisheries interdependencies considered in this paper are both biological and technological. Biological interdependencies exist when fish stocks have either competitive of predator-prey relationships. Technological interdependence exists when the harvest of one stock of fish leads to the bycatch of another stock. The simulation model incorporates both types of interdependencies. The mathematical programming model derives optimal allocations of effort according to a specified maximization criterion, subject to specified constraints.

Development of a fishery on northern squawfish on the Columbia River will very likely involve the development of management policies which will need to incorporate the biological interdependence between squawfish and salmonids. Mathematical programming may offer a tool for arriving at the appropriate harvest level for squawfish, once the relevant constraints are defined.

Keywords: fisheries, interdependence, biological, technological, simulation modeling, mathematical programming.

Beddington, J. and R. May. 1977. Harvesting natural populations in a randomly fluctuating environment. Science 197:463-465.

Abstract: As fishing effort and yield increase, fish populations that are being harvested for maximum sustainable yield (MSY) will be more sensitive to and take longer to recover from environmentally imposed disturbances. One consequence of this is that the variability of the yield, as measured by the coefficient of variation, increases as the point of MSY is approached. When overexploitation has resulted in a population smaller than the population associated with MSY, high effort levels produce a low average yield with a high variance. These observations are consistent with observed trends in several fisheries. The authors expect that these effects will be more pronounced for harvesting strategy based on constant quotas than for one based on constant effort. The same conclusions apply of the goal is to maximize the present value of the discounted net economic revenue from the fishery.

If a sustainable fishery is to be developed on northern squawfish for the purpose of predator control, the stock dynamics outlined in this article would be important to know. The anticipation of these effects of MSY harvest levels will help avert some undesirable consequences.

Keywords: fishery harvest, MSY, variability, sustainability, quotas, effort.

Berkes, F. and D. Pocock. 1987. Quota management and "people problems": a case history of Canadian Lake Erie fisheries. Transactions of the American Fisheries Society 116:494-502.

**Abstract:** This paper presents a case-study of harvest quotas allocated to individual fishermen in the Canadian Lake Erie commercial fisheries (rainbow trout, smelt, yellow and white perch, white bass, and walleye). The experience reported encompasses four years of plan development and three years of implementation. The recent trend in commercial fisheries management is toward limited entry with harvest quotas. An allocated catch quota system directly counters the common property concept, since the quota represents property rights to the resource. The quota also directly controls the total amount of fish that can be landed. The major issue underlying quota implementation in Lake Erie was fish stock assessment. A good biological data base and subsequent monitoring are required to scientifically estimate the total allowable catch of each species. Other issues were the political problem of how to allocate the total catch among eligible fishermen and enforcement of regulations. Comanagement by fishery managers and fishermen helped solve problems of catch allocation and enforcement.

Political and social considerations (equity) were more important to fishermen than economic efficiency. A research protocol is outlined for implementation of a quota system. Baseline data are needed, not only on fish stocks, but also on harvest technology, extent of capitalization,and socioeconomic characteristics of fishermen. Evaluation of the success or failure of the quota system in terms of specific criteria relating to the objectives of the management plan is essential.

This article has important implications for the development of commercial fisheries in northern squawfish in Columbia River reservoirs. A controlled, limited-entry fishery with total harvest quotas would probably have the best probability of achieving management objectives. Scientific evaluation of both biological and socioeconomic factors are necessary in order to implement the fishery and to demonstrate the efficacy of a predator control fishery to enhance salmonid populations.

**Key Words:** fishery regulation, harvest quotas, allocation, comanagement, freshwater fisheries.

Bishop, R.C. and K. Samples. 1980. Sport and commercial fisheries conflicts: a theoretical analysis. Journal of Environmental Economics and Management 7:220-233.

**Abstract:** The thesis of this paper is that commercial fisheries and recreational fisheries are often competing for a finite resource. Policy decisions to resolve these conflicts should be based on sound economic analyses at both the theoretical and empirical levels. A recreational component was added to a standard optimal control model of commercial fishing to identify public decision variables for optimal fish stock levels and optimal allocation of harvest between commercial and sport fisheries. A predator-prey component was added because of potential interactions between commercially important prey species (alewife) and recreationally important predators (salmon). Conclusions from the modeling were: 1) multiple use of fishery resources may be optimal; 2) the relative merits of sport and commercial fishing must be compared at optimal (not just existing) population levels; 3) it is important to consider benefit and cost functions over a variety of population sizes when evaluating alternative management strategies; 4) when more than one species of fish is involved, interactions such a predator-prey relations must be considered. The authors also question the point of view that sport fishing should be favored over commercial fishing since it is inherently more valuable; the comparison of values used is often invalid because the market value of commercial fish is compared to the value of the entire recreational experience.

The model development presented in this paper is relevant to the question of the economic value of developing recreational versus commercial fisheries on northern squawfish. However, the relative value of the two types of fisheries on squawfish is of secondary importance, because the major social benefit will probably be the enhancement of salmonid production. Therefore the primary criterion is the effectiveness of a fishery type in sustaining a reduction in squawfish populations, not the value of the fishery products. The model is also relevant to squawfish-related problems because it includes predator-prey interactions. In our case the commercial fishery would be developed on the predator instead of the prey; in this way the squawfish fishery has the potential to enhance both sport and commercial fisheries on salmon and steelhead. The predator-prey mechanism developed to evaluate conflicting use in this model may be a basis for further development in analyzing the synergistic effects of the salmonid and squawfish fisheries on the Columbia River.

Key Words: commercial fisheries, recreational fisheries, conflicts, predator-prey, multiple use, optimal population levels.

Boyle, K.J. and R.C. Bishop. 1987. Valuing wildlife in benefit-cost analyses: a case study involving endangered species. Water Resources Research 23(5):943-950.

Abstract: This paper is concerned with the identification of relevant values in benefit-cost analyses that may affect wildlife or its habitat. A conceptual framework for examining the total value of a wildlife resource is developed and applied to valuation of two endangered species in Wisconsin; bald eagles and striped shiners. The components of value for wildlife resources are first discussed, with emphasis on those particularly relevant to endangered species. There are three basic groupings of use values: consumptive use value (hunting, fishing, trapping), nonconsumptive use value (viewing wildlife), and indirect use values

(reading about wildlife, watching television specials about wildlife). An individual may hold more than one of these values for a specific wildlife resource. A theoretical model of individual preferences is next proposed to examine the relationships among different values and to determine their relationship to total value. Contingent valuation methods are used to estimate values for bald eagles and striped shiners. Empirical results indicate that Wisconsin taxpayers place a significant aggregate monetary value on the preservation of these two endangered species. The authors conclude that to overlook values for wildlife that go beyond common use values may result in misleading policy decisions.

Valuation techniques such as the method described in this paper may be used to estimate publicly-held values for resources which do not pass through market channels. This policy area would include the development of a recreational fishery on a previously unexploited species, such as squawfish, carp, or suckers. If the objective were to greatly reduce or eradicate a species (e.g. northern squawfish) with a control fishery, the concept of intrinsic existence values would be important in the evaluation of economic benefits of the management action. However, since the northern squawfish control fishery is conceptualized in terms of sustained moderate exploitation (about 20%), the main values of interest are the use values. If the total valuation concept were used for an economic analysis of the Columbia River fishery resources, it would probably tip the scales further in favor of managing for enhancement of salmonid species by reducing squawfish populations, since several salmonid stocks have been depleted or eliminated.

**Keywords:** wildlife, valuation, consumptive use value, nonconsumptive use value, indirect use value, preservation.

Cauvin, D. 1980. The valuation of recreational fisheries. Canadian Journal of Fisheries and Aquatic Sciences 37: 1321-1327.

**Abstract:** At present, recreational fisheries are generally considered a non-priced (free) resource, based on the proposition that natural resources are a public heritage from which no member of society should be excluded. The validity of recreational fishing valuation techniques (expenditures, travel cost, value added, and willingness to pay methods) are questionable, and are poor substitutes for a price system. The author argues a need to adopt a pricing system to value recreational resources in order that equitable allocation decisions might be made, and that government management programs should be accountable for their allocation of resources. The major reason for not always pricing recreational use of fishery resources is that the costs of fee collection and enforcement may exceed benefits. Conventional wisdom suggests that the multifaceted nature of the recreational fishing opportunity makes rational pricing of recreational fishing very difficult, and perhaps impossible.

Recreational fisheries on northern squawfish in the Columbia River are negligible; the present recreational value of this resource may be considered zero. It is doubtful that anyone would pay for the opportunity to fish for squawfish under present conditions without additional incentives and organized promotion. However, since enjoyment of the fishing experience is generally considered of greater value than the food value of the fish caught, it is feasible that a recreational fishery could be developed on this resource. The recreational value of fishing for squawfish may be enhanced if the participants had a sense that they were benefitting the salmon fisheries by reducing predation.

Key Words: recreational fisheries, price system, valuation, multidimensional character of recreational fishing.

Charbonneau, J.J. and M.J. Hay. 1978. Determinants and economic values of hunting and fishing. Transactions of the North American Wildlife Conference 43:391-403.

Abstract: Better methods of monetary valuation of recreational hunting and fishing are needed for enhancing decisions related to the costs and benefits of fish and wildlife and their habitat compared to alternative uses of land such as industrial and agricultural development. The purpose of this paper is to summarize several studies based on data collected by the 1975 National Survey on Hunting, Fishing, Wildlife, and Associated Recreation, conducted by the U.S. Fish and Wildlife Service. Economists usually agree that consumer surplus is the appropriate measure of benefits which sportsmen derive from hunting and fishing that are attributable to the fish and wildlife resource. Consumer surplus is the amount an individual would pay to hunt or fish, above his or her actual expenses. Two approaches to estimating consumer surplus are discussed: 1) a direct question, willingness to pay method, and 2) an indirect method that derives value estimates from individuals' expenditures. Methods were applied to an example related to waterfowl hunting. Forecasting equations, when combined with estimates of economic values of hunting and fishing, can provide better information for assessing management alternatives.

This article discusses methods which are used for the valuation of recreational hunting and fishing. At present there is no appreciable recreational fishery on northern squawfish on the Columbia River. Predicting the monetary value of a recreational fishery on squawfish is beyond the scope of the current research project, and the data necessary for making such an estimate are lacking. If a recreational fishery were developed, it would be important to evaluate the fishery and collect the data needed for economic analyses of this type.

Keywords: fishing, hunting, recreation, valuation, consumer surplus, willingness to pay, expenditures.

Copes, P. and J.L. Knetch. 1981. Recreational fisheries analysis: management modes and benefit implications. Canadian Journal of Fisheries and Aquatic Sciences 38: 559-570.

Abstract: The purpose of this paper is to extend the theoretical analysis of recreational fisheries economics in order to integrate recreational and commercial fisheries management. The development of a common analytical base for recreational and commercial fisheries is essential if rational policy decisions are to be made on management of fish stocks which are jointly exploited by the two types of fisheries. The economics of commercial fisheries has generally been analyzed in terms of fundamental bioeconomic relations between sustainable yields and levels of fishing effort. In contrast, recreational fisheries have been analyzed as demand of consumers for opportunities to fish as a recreational pursuit--including intangibles related to the quality of the fishing experience. The common criteria for examining optimum utilization of the resource is the magnitude of benefits generated. One common denominator, to relate commercial and recreational fisheries, is the number and size of fish taken. In order to link commercial and recreational theory, the complex relation between the value of sport fishing enjoyment and the amount of fish taken must be determined. A major difference in the economics of the two types of fisheries is that commercial fish products are directly priced to the consumer, while sport fishing opportunities are provided free. The non-market nature of recreational fishing makes its valuation more difficult; but conceptually, the economic value of a product (fish) or service (sport fishing opportunity) is the same--what people are willing to give up to obtain it.

In the case of the development of fisheries on Columbia River northern squawfish, managers under ordinary circumstances would assess commercial versus recreational fisheries in terms of their relative benefits to society. However, since the main benefit to society may be the enhancement of salmonid fisheries, this direct comparison of benefits is not as relevant to the overall management strategy. Instead, the two types of fisheries would be compared in terms of the relative cost and effectiveness of a bounty system applied to either a commercial (subsidized) fishery or a recreational (tournament) fishery to achieve a desired measurable level of exploitation of the squawfish population. Initially, the benefits of the fishery products would just help defray the costs of developing and subsidizing the fishery. In the long run, however, economics are important because the self-sustainability of the fishery in the absence of bounty incentives will probably determine the effectiveness of this management measure as a salmonid enhancement technique.

Keywords: recreational fisheries, commercial fisheries, joint exploitation, valuation, optimum utilization.

Crutchfield, J. 1965. Can we put an economic value on fish and wildlife? Colorado Outdoors 14(2): 1-5.

**Abstract:** Water and land utilization are increasingly subject to more sophisticated techniques of evaluation and long-range planning. As those plans involve fish and wildlife decisions that are for practical purposes irreversible, economic techniques that fall within the confines of accepted practices of other water uses are essential. Valuation of fish and wildlife has been made more difficult by the insistence of many groups that hunting and fishing must be available at no cost. In the absence of a market, simulation studies are effective for economic valuation of fish and wildlife. Although conceptually correct, simulation studies are expensive. The author recommends that more intensive economic analysis be used as a basis for investment in fish and wildlife.

Valuation questions apply directly to the assessment of fishery development feasibility of squawfish. The trade-off between squawfish capture and salmonid predation implies a positive economic value--measured in terms of surviving juvenile salmon--to the harvest of squawfish. Whether the value of squawfish is a net positive value depends on the costs of harvest relative to returns from squawfish use and to the value of surviving salmon.

**Keywords:** economic valuation, fish, wildlife, investment.

Duttweiler, M.W. 1985. Status of competitive fishing in the United States: trends and state fishery policies. Fisheries 10(5):5-7.

**Abstract:** This paper reports on a survey of state agencies which updates the survey conducted by Shupp (this bibliography). The survey had 5 objectives: 1) to determine recent trends in black bass fishing; 2) to obtain an initial measure of competitive fishing for other species nationwide; 3) to describe the positive and negative impacts of competitive fishing as ascribed by managers of fishery resources; 4) to describe current state management posture toward competitive fishing; 5) to identify research and policy needs associated with competitive fishing. The survey found the following: competitive fishing for black bass continues to dominate tournament fishing in the U.S. Management agency perceptions of the impact of tournament fishing did not change appreciably between 1978 and 1985 except for an increased appreciation for both positive media coverage and negative impacts of concentrated fishing effort. Also identified were needs for information dissemination on fish mortality, catch and release methods, and fishing conflicts.

The survey information summarized in this paper on tournament fishing will provide a useful identification of the major issues which will face Columbia River fishery managers if tournament fishing develops for northern squawfish. The experience of state agencies with black bass fishing tournaments will allow a more efficient development of this method of fishing as well as the avoidance of predictable conflicts.

Keywords: competitive fishing, survey, state agencies, impacts

Hannesson, R. 1983. Optimal harvesting of ecologically interdependent fish species. Working paper, Institute of Economics, University of Bergen, Norway.

**Abstract:** This paper considers the optimal exploitation of a two species predator-prey system. Due to the density-dependence of ecological efficiency, both species should be harvested simultaneously over a range of relative prices. Beyond the limits of this price range, either the prey species should be utilized indirectly by harvesting the predator, or the predator should be eliminated in order to maximize the prey yield. Certain results from single species fishery models are shown not to apply to multispecies models. These are: 1) optimal regulation of a free access fishery may call for subsidizing instead of taxing the harvest of predator species; 2) increasing the discount rate may, at "moderate" levels, imply that the optimal standing stock of biomass increases instead of decreases; 3) a rising price or a falling cost per unit of effort of a species may raise and not lower the optimal standing stock of that species.

The modeling effort reported in this paper has direct implications for the development of a fishery on northern squawfish. Choices between yield of predator and prey, as described in this paper, depend critically on relative values of the two species. These are the types of management choices that will be made for squawfish-salmon interactions and the fishery on each species.

Keywords: predator-prey, optimal exploitation, relative prices, management techniques.

Higgs, E.S. 1987. Changing value perspectives in natural resource allocation: from market to ecosystem. Transactions of the American Fisheries Society 116:525-531.

**Abstract:** Traditional approaches to natural resource allocation--deciding who gets what--have been based on economic considerations. The author argues that it is no longer adequate to simply apply market-driven criteria to questions of resource allocation. Recently the values underlying resource allocation have shifted to a more "moral" position based on heightened concern for the total environment. An ecosystem approach to allocation is advocated in which policy makers, resource users, and society decide on the desired future resource condition before deciding on the means of allocation. This approach brings values to the forefront of the decision process. However, mechanisms for instituting held values in the allocation process are not well-developed.

Development of a fishery on northern squawfish in the Columbia River will require the same type of "ecosystem" approach described in this paper. Because the procedures for accomplishing this are not well-developed, fishery development of squawfish would provide a good laboratory for the experimentation with different techniques to achieve equitable allocation.

Keywords: resources, allocation, values, ecosystem.

Holbrook, J.A.II. 1975. Bass Fishing Tournaments. In H. Clepper, ed., Black bass biology and management. Proceedings of a National Symposium on the Biology and Management of Centrarchid Basses, Tulsa, Oklahoma, February 3-6, 1975. Washington, D.C.: Sport Fishing Institute.

Abstract: This paper reviews the organization and conduct of national black bass fishing tournaments through 1975. Included in the review are summaries of tournament rules and procedures, the relationship of tournaments to overfishing, mortality studies, regulations, catch per unit effort, and uses of tournament-caught fish. The author stresses the opportunity to research biologists provided by tournament catch in the assessment of black bass populations. Research opportunities are seen as the most important effect of bass fishing tournaments.

If tournament fishing for northern squawfish is developed on the Columbia River, this review of tournament organization and conduct nationwide will provide guidance for the components of a competitive fishing system, as well as for research opportunities afforded by tournament catch.

Keywords: national fishing tournaments, regulations, research.

Hummel, R.L. and G.S. Foster. 1986. A sporting chance: relationships between technological change and concepts of fair play in fishing. Journal of Leisure Research 18(1):40-52.

Abstract: This paper examines ideas about fair play (sportsmanship) and technological change in fishing. Fishing "technology" includes the tools of fishing, techniques of using those tools, knowledge of the prey and its environment, and knowledge of the effects of fishing tools on populations of prey. "Fair play" is defined as conduct according to the rules of the game which specify acceptable means of pursuit of particular goals. Rules may have either informal or formal origins. The essence of sport is contrived, self-imposed difficulties in pursuit of some goal. Historically, sport fishing arises only when fishing is not required for subsistence. The technology of sport fishing includes the following elements: decisions about target species, access to habitat, fishing gear, knowledge of use of fishing gear, knowledge of fish behavior and habitat.

Definitions of fair play vary widely according to fishery circumstances. The concept of fair play is multi-dimensional. Variations exist in value orientations (e.g. democratic vs. elitist), goals (most/biggest fish vs. most difficult fish), means (technology vs. craftsmanship), standards of performance (performance results vs. performance quality), rewards (external vs. internal), participants (mass appeal vs. selective appeal), and technological change (promoted vs. resisted). The historical record shows that significant technological advances in sport fishing have induced changes in the standards of fair play.

The concepts outlined in this paper have a direct bearing on the interaction between various fisheries for northern squawfish and other established fisheries. Notions of fair play also have implications for the conduct of a fishery for northern squawfish that should be incorporated into the planning stages of fishery development.

**Keywords:** sport fishing, technology, fair play.

Knetsch, J.L. 1963. Outdoor recreation demands and benefits. Land Economics 39:387-396.

**Abstract:** This author discusses the difficulty with assigning values to resources used for recreation. Public agencies would like to provide a level of recreational resources commensurate with public preference but must make decisions in the absence of prices, the usual expression of value. Other means must be found of measuring consumer willingness to pay for recreation. This article focuses on travel costs and other costs as proxies for market value. In addition, income, site congestion and recreational alternatives are also factors in the demand for recreation. It is also difficult to fully account for benefits received by recreational users, because many recreational benefits are nonmaterial.

The types of analytical difficulties in recreational valuation that are described in this article will be factors in the assessment of a fishery on northern squawfish on the Columbia River. The decision to allocate the fishery to commercial or recreational users or to a combination of the two will be made more difficult without clearly defined values for recreational use.

**Keywords:** recreational resources, demand, benefits.

Loomis, D.K. and R.B. Ditton. 1987. Analysis of motive and participation differences between saltwater sport and tournament fishermen. North American Journal of Fisheries Management 7:482-487.

**Abstract:** Existing studies establish the heterogeneity of fishermen. This paper reports on empirical tests for differences in motivation between saltwater sport

anglers and saltwater tournament fishermen in Texas. A focus of the research was the differences in catch-related and noncatch motivations between these two groups. Catch-related motivations are represented by 13 different measures, including catching a trophy fish, the fishing challenge, developing skills and testing equipment. Noncatch related motivations are represented by 6 measures, including being with friends, family recreation, being outdoors, and relaxation. Saltwater tournament fishermen were found to differ from saltwater sport fishermen on measures of catch-related motivation but not on measures of noncatch-related motivation. Not surprisingly, tournament fishermen are more oriented towards catching bigger fish and more fish. The identified characteristics of tournament fishermen have direct implications for fishery management, particularly of stressed populations. Tournament organizers should be encouraged to either direct effort on species with healthy populations or institute catch-and-release programs as part of the tournament structure. Creel limits are a further management option.

Differences in fisherman motivation create a potential for conflict between different types of fisheries. These differences should be kept in mind for the development of fisheries on northern squawfish, both in terms of conflicts which may arise between a northern squawfish fishery and other more established fisheries as well as in terms of conflict which may arise between different types of fisheries on northern squawfish.

Keywords: fishermen heterogeneity, fishing motivation, catch-related motivation, noncatch motivation, tournament management.

Martin, L.R.G. 1987. Economic impact analysis of a sport fishery on Lake Ontario: an appraisal of method. Transactions of the American Fisheries Society 116:461-468.

Abstract: A Keynesian-type economic impact analysis (EIA) was applied to the sport fishery in the Bay of Quinte, Lake Ontario in 1985 and 1986. EIA measures the direct, indirect, and induced consequences of resource development to a region, but does not assign an explicit value to the fishery resource. It is one facet of socio-economic impact assessment which can be used to forecast the social and economic consequences of resource development projects, thus providing managers and policy makers with valuable information for making decisions. EIA enables fishery managers to relate management decisions which cause a change in sportfishing activity to the effect on the regional economy in terms of sales, incomes, and jobs. An angler survey was conducted to collect detailed socioeconomic data. The methodology is outlined in the context of information needs of resource managers and planners. EIA can indicate the role of sportfishing in economic development and tourism, identify the relative contributions of angler groups, identify impacts on businesses, and suggest approaches to strengthen a region's intersectoral linkages in order to maximize impact.

There is a potential need for a socioeconomic analysis of the effects of northern squawfish fishery development (commercial, bounty, or sport) on the regional economy. Such an analysis would have to be justified on the grounds that its results would help fishery managers and policy makers evaluate the relative merits of various predator control and salmonid enhancement measures. If this rationale were developed, then the appropriate methodology could be chosen on the basis of data requirements, cost, and desired accuracy and sophistication of results.

Keywords: freshwater fisheries, recreation, economic impact, EIA, economic development, tourism.

Martin, W.E., F.H. Bollman, and R.L. Gum. 1982. Economic value of the Lake Mead fishery. Fisheries 7(6):20-24.

Abstract: The economic value of Lake Mead, Colorado River as a hydroelectric power producer and source of water supply can be estimated from market prices; however, it is more difficult to estimate the value of its warm-water recreational fishery because a conventional market does not exist. The purpose of this paper is to estimate the value of the present fishery as input to the water management process. The Clawson-Hotelling method of developing a non-observed demand curve was used to estimate the value of nonmarket goods and services. Interviews with fishermen were used to gather data needed to develop the demand equation. First, a demand curve for the entire recreational experience is developed, next, a second-stage demand curve for the fishing activity itself is derived. Empirical data from individual fishermen are statistically fit to demand curves; these are summed to form aggregate demand curves for the fishery. Consumer surplus is the satisfaction a consumer receives from a commodity above the actual price paid. This measure may be interpreted as the total net value of the resource site to the fisherman for fishing. Since there is no entry fee for fishing at Lake Mead, the entire area under the demand curve for the site measures the quantity of consumer surplus generated.

At present there is a negligible recreational fishery for northern squawfish on the Columbia River. If squawfish derbies or tournaments were initiated to reduce predator numbers, however, the consumer surplus valuation technique may be a way to analyze recreational value derived by the public. This method may also be used to value existing sport fisheries on resident game fish (e.g. walleye) in comparison to existing sport and commercial fisheries on salmon, and potential commercial or bounty fisheries on northern squawfish.

Keywords: recreational fisheries, valuation, demand for fishing, consumer surplus.

Matlock, G.C. 1986. Estimating the direct market economic impact of sport angling for red drum in Texas. North American Journal of Fisheries Management 6:490-493.

**Abstract:** In this article the author develops a method for estimating the direct market economic impact of a sport fishery and applies this method to red drum (Theienops oceeconomicglers in Tevalue of recreationally caught fish can be measured in five ways: 1) market value of the catch, or direct expenditures to enter the fishery; 2) direct and multiplier effects of expenditures on local economies; 3) all direct and associated participation costs of the fishery; 4) the value placed on the fishing experience by the participant; 5) willingness to pay for the opportunity to participate. These approaches have problems, including difficulties in verification. As an alternative approach, the author estimated the direct market impact of the sport fishery for red drum in Texas by subtracting the market value of the fish from the total direct expenditures by red drum anglers. This approach assumes a commercial market for sport caught fish. The advantage of this approach is that it allows a direct comparison between sport and commercial fisheries in terms of direct economic impacts to determine how different allocations between sport and commercial fisheries would affect a region economically.

This approach would have direct bearing on allocation issues related to northern squawfish if opportunities for both commercial and recreational fisheries existed. If enough market demand exists for squawfish to make a commercial fishery economically feasible and if recreational demand also exists, managers may well face this type of allocation problem.

**Keywords:** recreational fishery, economic impact, allocation.

May, R., J. Beddington, C. Clark, S. Holt, R. Laws. 1979. Management of multispecies fisheries. Science 205(4403):267-277.

**Abstract:** Setting maximum sustained yield figures for individual species is an inadequate management strategy for multispecies systems. Models of krill-baleen whale interaction are used to illustrate the way multispecies fisheries respond to harvesting at various trophic levels. Economic aspects of harvesting multispecies fisheries are considered primarily for the purpose of improving acceptability and predictability of management regimes. Overexploitation of fisheries arises from the lack of strong property rights among fishermen to current and future fish. Uncertainty in biological systems also has important economic implications and creates conflicting responses by biologists and fishermen. Under uncertainty biologists will promote conservative management strategies but fishermen will discount future returns heavily and thus show an opposite response. Contingency

plans to deal with unexpected changes are especially important for multispecies systems, although proper target levels for various species are difficult to determine. Multispecies systems often exhibit complex discontinuities in response to fishing or environmental change.

The authors reach several tentative conclusions about the management of multispecies systems. 1) For populations not subject to significant predation, MSY may be useful. 2) Ecosystem preservation requires that stock of a prey species not be reduced to levels affecting its own or other species productivity. 3) Time scales affecting population processes must be kept in mind. 4) Environmental stochasticity will cause population parameter estimates to fluctuate. 5) Multispecies systems have complex biological-economic-political interactions not found in single species systems.

Management of a squawfish fishery may well require techniques appropriate to the management of multispecies systems. Exploitation could occur simultaneously on stocks of squawfish, suckers, and carp. Further multispecies considerations will include those species which are not targeted in or caught by the squawfish/ suckers/carp fishery but which interact with these species biologically.

Keywords: multispecies, management, species interactions, uncertainty.

Milliman, S.R., A.P. Grima, and C.J. Walters. 1987. Policy making within an adaptive management framework, with an application to lake trout (Salvelinus namaycush) management. Canadian Journal of Fisheries and Aquatic Management 44(Suppl. 2):425-430.

Abstract: In this paper the authors combine adaptive management techniques with concepts of natural resource economics to create a practical method for making policy choices in fisheries. The most appropriate fishery management action is that policy which is most likely to advance important socioeconomic objectives such as enhanced economic welfare, greater cultural opportunities, and species preservation. Uncertainties about the biological impact of various policies often impedes optimal policy choice. Lake trout (Salvelinus namaycush) rehabilitation in the Laurentian Great Lakes is used as an example. Uncertainties which impede the progress of lake trout rehabilitation are reviewed. These include uncertainty about recovery rates, sustainable exploitation rates, vulnerability to various sources of mortality, and lamprey predation. Next, a framework is proposed for developing a set of policy options which incorporate uncertainty, treating the uncertainties listed above as the focus for monitoring activities. Included in these options are "actively adaptive" policies which are experimentally designed to revive the lake trout fishery and yield data which may lessen uncertainties. The authors use basic concepts from natural resource economics such as net social and economic benefits, discount rates, time horizons, and expected value to outline how, in the presence of uncertainties, the policy which is most likely to maximize socioeconomic gains can be chosen from the various options. The strength of the adaptive management approach is its attempt to anticipate uncertainties and surprises and to incorporate new information in the process of fishery policy development.

Development of a fishery on northern squawfish will include an experimental phase in which different policy designs are applied. Adaptive management techniques seem to offer the best possibility for building a management strategy that incorporates both biological and economic uncertainties and the production of new information.

**Keywords:** fisheries policy, uncertainty, adaptive management.

Nielsen, L.A. 1985. Philosophies for managing competitive fishing. Fisheries 10(3):5-7.

**Abstract:** This paper identifies four prevalent theories of fisheries management which influence the way public agencies approach competitive fishing. "Protectorism", a philosophy of many resource managers, sees competitive fishing as a destroyer of vulnerable aquatic resources and of traditional fishing methods. "Brokerism", the most common philosophy of fisheries management, is the process of making decisions on the basis of public consensus. Brokerism remains special interest politics unless there is full public participation. Brokerism must include fishing competitions because of their popularity. "Rationalism" is the underlying principle of optimum sustained yield; it seeks to find the maximum public benefit from the fishery resource given the full information about tradeoffs. As such, rationalism sees competitive fishing as part of the overall allocation problem facing fishery managers. A limitation to rationalism is that full information is never available and managers must operate in an environment of uncertainty. "Pragmatism" demands full utilization of resources within the constraints of an agencies mission and regulations. This point of view accepts competitive fishing as a fact and makes the best of it. The author asserts that a single resource management philosophy is not appropriate for all situations. A recognition of the spectrum of philosophies should foster communication between different points of view.

The development of new fisheries on northern squawfish will require coordination between different fishery management agencies. The identification of different fishery management philosophies is useful in the anticipation of different approaches to management which may arise between management entities on the Columbia River, as well as in the prevention of management conflict.

**Keywords:** competitive fishing, management philosophy, protectorism, brokerism, rationalism, pragmatism.

Pearse, P.H. 1969. Toward a theory of multiple use: the case of recreation versus agriculture. Natural Resources Journal 9:562-575.

**Abstract:** The concept of "multiple use" has not been rigorously evaluated in terms of the critical issue of conflicting demands. The purpose of this article is to demonstrate the kind of information required to determine the socially optimum aggregate of conflicting uses of a natural resource, and clarify the criteria for establishing the optimum combined value. Production theory, based on biological concepts such as competition and carrying capacity, incorporates the relative value of alternative uses and provides reliable criteria for deciding the optimum combination of two or more competing uses of a fixed resource. Various kinds of investments in the resource can be evaluated in terms of increased total output and efficiency of alternative forms of enhancement. The assumed objective of multiple use has been to maximize the contribution of the resource to the welfare of the social group in whose interest it is managed. The highest value of a resource is derived by a combination of uses specified by the confrontation of a set of purely technical relationships with a set of economic ones. The biggest economic problem is establishing the value of resources which are provided free to users.

There are likely to be conflicting multiple uses of the northern squawfish resource if a Columbia River fishery for this species is developed. These will include sustaining the direct economic benefits of new fishery products, population control to reduce juvenile salmonid mortality, and achieving a balanced resident fish community, i.e., mediating compensatory mortality relationships with other predatory species.

**Keywords:** recreational fisheries, multiple use, conflict, production theory, investment evaluation, resource value.

Peyton, R.B. 1987. Mechanisms affecting public acceptance of resource management policies and strategies. Canadian Journal of Fisheries and Aquatic Sciences 44( Supplement 2):306-3 12.

This article addresses the problem of management issues arising from Great Lakes rehabilitation efforts. Several issues require management: scientific and technological inadequacies, incomplete and/or conflicting public beliefs, and conflicting public values. This paper discusses the components of resource issues, the dynamics of public perception and response, and the role of public involvement in implementing management programs. A major component of resource issues is the adequacy and nature of science. Public education attempts have traditionally focused on the information products of science rather than the scientific process. This leaves the public without realistic expectations of the scientific basis for management. Another component of resource management issues is the conflicting values held by various groups. Additional factors with which resource managers must deal are the attitudes and behavior of the public. An important distinction exists between the goal of public acceptance of resource management and the process of public involvement. Public involvement may have a number of goals, including public acceptance. Public acceptance of a management program may be gained by several strategies, including public involvement. Resource agencies could better determine factors which determine public response to management programs if staff were trained to deal with the public dimensions of management. Especially important is the need for expertise to involve the public in resolving different value conflicts in issues. Resource managers must invest in long term programs to build rapport and credibility with the public, improve the public's understanding and participation in the management process, and gain a better understanding of the segments of the public affected by resource management.

The issues outlined in this paper are likely to be issues of importance in the development of a fishery on northern squawfish on the Columbia River. A key issue to be kept in mind during the fishery development phase is public perception of the management process. Public involvement in the design and implementation of policy for a new fishery should contribute substantially to public acceptance.

**Keywords:** resource management, conflicting values, beliefs, goals, public acceptance.

Pringle, J.D. 1985. The human factor in fishery resource management. Canadian Journal of Fisheries and Aquatic Sciences 42:389-392.

**Abstract:** Scientists and managers often assume fishermen oppose resource management when fishermen disregard a management plan developed without consultation or in an unclear manner. This paper argues that resource manager-fishermen relations are a critical, but often ignored, variable in the resource management equation. To permit good science to become good management, scientists, resource managers and fishermen must communicate effectively. Experience suggests that scientists and managers rarely look at the system of fishery resource management from the fisherman's perspective. The bulk of the regulatory decisions have been made by non-fishermen and in spite of regulations, many of our stocks have not been well-managed. Two case studies of fishery management are provided--one an example of successful cooperative government/ fishermen management and a second, contrasting example of unsuccessful management designed without fisherman input. The author concludes with an appeal to scientists and fishery managers to look at government's performance in resource management from the perspective of fishermen, to approach management with the operating assumption that fishermen care for their resource, and that industry and government cooperation in management may be formalized.

This paper identifies fisherman involvement as a key factor in the success of fishery management. Development of a fishery on northern squawfish is likely to proceed more smoothly if fishermen are involved from the beginning in the design and formulation of regulations.

**Keywords:** resource management, fishermen, consultation, communication.

Propst, D.B. and D.G. Gavrilis. 1987. Role of economic impact assessment procedures in recreational fisheries management. Transactions of the American Fisheries Society 116:450-460.

**Abstract:** Economic impact assessment (EIA) methodologies are analytical tools used to expose regional and interregional structures, to explain regional growth, and to help resource decision makers describe the effects of various policies and investments. At the federal level, benefit-cost analysis is used as a measure of efficiency of a government project in terms of the direct value of goods and services. The EIA is a value-free description of an economy at one point in time and is concerned primarily with the effects of total consumer expenditure. The EIA was developed as a descriptive method, but it can incorporate multipliers in order to achieve predictive capabilities. In recreational fisheries, typical "ratio multipliers" should not be applied to consumer spending for computation of total impacts; instead, a Keynesian relationship, which expresses additional impacts per unit of consumer spending, should be used. The hybrid data input-output model can satisfy the widest range of fisheries information needs. Theoretical and conceptual model development generally is more advanced than the empirical data base. At present, high quality data for the EIA of investment in fishery resources does not exist.

The EIA may be a useful method to evaluate the effect on the regional economy of the development of a commercial, bounty, or recreational fishery on northern squawfish. Perhaps the most important benefit derived from such a fishery would be the enhancement of salmonid populations. It would be difficult to quantify the incremental benefit of increased salmonid production derived from a northern squawfish removal fishery because of the concurrent interactions of a complex of salmonid enhancement measures targeted at a variety of detrimental factors, coupled with the inherent variability of the system. The foresight of gathering economic data within the framework of an analytical tool such as the EIA may facilitate the development of a comprehensive control fishery evaluation program in the future.

Keywords: recreational fisheries, management, economic impact assessment, data quality.

Regier, H.A. and A.P. Grima. 1985. Fishery resource allocation: an exploratory essay. Canadian Journal of Fisheries and Aquatic Science 42:845-859.

**Abstract:** The authors explore several approaches to the problem of allocation of fishery resources. Interest is now growing in allocation because in most industrialized countries the complex of direct and indirect uses of ecosystems has led to environmental degradation and an increasing number of interactions among the effects of different user groups. Allocation and reallocation of rights to aquatic resources often occurs in a haphazard or covert way which is divisive and unjust to some user groups. This article addresses the problem of how to reduce the improprieties of allocations and at the same time enhance good husbandry to prevent environmental degradation. The authors propose a series of guidelines which are designed to improve the allocation process. A number of societal means to the allocation of rights are identified, including markets, legal tribunals, administrative tribunals, and community negotiations. There is a need for a clearer specification of rights to a fishery as well as a need for improvements in the means by which those rights are allocated.

Allocation rights to northern squawfish and its associated species will need to be clearly specified if a fishery is developed. The guidelines presented in this paper will be helpful in building an allocation scheme that recognizes the rights of various interest groups and is therefore less likely to be divisive.

**Keywords:** fisheries, resource allocation, formal rights, informal rights, environmental degradation, husbandry.

Rettig, R.B. 1987. Bioeconomic models: do they really help fishery managers? Transactions of the American Fisheries Society 116:405-411.

**Abstract:** Pacific Northwest salmon managers have dealt with management crises for more than a century. Management responsibilities have increased in recent years with new user groups, new management regimes, increased enhancement and mitigation efforts, and concern about the depletion of wild stocks. Planning and policy decisions are increasingly difficult. In response to progressively more complex management issues, computer models of increasing sophistication are being used. Managers need to know whether such models can assist them with two major categories of decisions: 1) How should a long-range fishery goal be modified to address short-run economic concerns, such as high unemployment levels? 2) What criteria should be used to allocate a limited quota among competing users? This author argues that social scientists should be aware that types of knowledge other than "scientific" knowledge will be incorporated into the policy process. A great deal of "ordinary" knowledge will be brought to the policy process through the inclusion of public advisory bodies. This ordinary knowledge

will be combined with scientific knowledge by managers. This has implications for the way social scientists construct bioeconomic models: managers should be incorporated in model building from the development stages onward, rather than consulted at the end of the modeling exercise.

Development of a bioeconomic model of the fishery on northern squawfish or of northern squawfish--salmon fishery interactions will be a likely analytical outcome of current fishery development potential. Such an exercise will require that managers be involved in model construction from the beginning if the resultant model is to be relevant to managers' needs.

**Keywords:** bioeconomic models, fishery management, scientific knowledge, ordinary knowledge.

Riley, L.M. 1985. Competitive fishing in Arizona: the need for biological or social management. Fisheries Branch, Arizona Department of Game and Fish. 7pp.

**Abstract:** An angling contest is defined in this paper as any organized fishing activity which results in evaluation of the catch and the awarding of prizes. Impacts of fishing contests fall into three types: biological impacts, economic impacts, and social or user group impacts. Four types of fishing contests are identified, listed in order of frequency of occurrence : tournaments (short in duration and site-specific), roadrunners (short in duration but not held at a specific site), derbies (long lasting), and kid derbies (short in duration, specifically for children).

On the basis of data collected from fishing contests in Arizona, this author reaches several conclusions about angling contest impacts. Angling contests do not appear to have more than minimal added impact to fish populations, over and above the effect of other recreational fishing. Large profits are not being made by competitive angling at the expense of Arizona's fishery resources. A final conclusion is that interactions between user groups are the areas needing management and education efforts.

This paper identifies issues related to competitive fishing which will provide useful guidance to the development of fisheries for northern squawfish. In the identification of impacts of competitive fishing, it is interesting to note that the most important areas identified for education and management efforts are conflicts between user groups.

**Keywords:** fishing contests, tournaments, derbies, recreational fishing, fisheries management, user groups.

Schlick, R.O. 1978. Management for walleye or sauger, South Basin, Lake Winnipeg. Pages 266-269 in Selected coolwater fishes of North America, R.L. Kendall, ed., American Fisheries Society Special Publication No. 11.

**Abstract:** Walleye and sauger are the main species comprising the commercial fishery in the South Basin of Lake Winnipeg, Manitoba. Gill net mesh size restrictions can be used to manage in favor of walleye (large mesh) or for the smaller sauger (small mesh). The more liberal 76mm gill net mesh would be more economically favorable for fishermen because it would increase the catches, but it would probably decrease the population of walleye because fewer numbers would reach reproductive size. Thus the 108mm mesh restriction would favor the larger walleye. Water transparency is an important environmental variable affecting the relative dominance of the two species--clear water generally favors walleye.

Consideration of size-selective fishing gear (such as gill net mesh size restrictions) would be an important economic consideration in terms of optimum size and numbers of northern squawfish commercially harvested in the Columbia River, and also in terms of management of other food and game fish such as walleye.

**Keywords:** freshwater fisheries, management, gear restrictions, optimum mesh size, economic tradeoffs.

Sharif, M. 1986. The concept and measurement of subsistence: a survey of the literature. World Development 14(5):555-577.

**Abstract:** Subsistence is a widely used concept in theoretical literature, empirical literature, and in the policy arena. Despite widespread use of the concept, its precise meaning is not well-understood. The author first examines the manner in which the concept of subsistence is used to refer to production and consumption activities. The concept of subsistence used in different economic theories is an absolute minimum standard of productive living, not just survival. In addition to survival needs, subsistence includes needs of physical and mental efficiency. Income level is one measure used to characterize the standard of subsistence. The author identifies three methods of determining subsistence-level living and finds the two most commonly used methods--social (direct observation of a society's minimum standard) and scientific (minimum mental or physiological requirements)--to be arbitrary. The third method--the behavioral method--identifies subsistence by observing the behavior of people at the lower level of the income distribution. The author concludes that the behavioral approach is the method which offers the most promising direction for measurement.

The regulatory review process and the policy development phase of the squawfish feasibility project could well identify a potential squawfish fishery as a tribal fishery. If this identification is the outcome the possibility of subsistence fishing may arise. This article will help to clarify the meaning of that concept.

Keywords: subsistence, survival, income, social minimum, behavior.

Shupp, B.D. 1979. 1978 status of bass fishing tournaments in the United States: a survey of state fishery management agencies. Fisheries: 4(6):11-19.

**Abstract:** Competitive fishing had spread to all areas of the United States by 1978. This paper reports the results of a survey of state fishery agencies about the impacts of bass tournaments, the magnitude of bass fishing activity, fishery policy toward bass tournaments, degree of agency involvement in tournament activity, and opinion about the impact of tournaments on fish populations. Survey results identified several common aspects of tournament fishing. Conflicts between tournament and nontournament anglers are common. Developing tournament fisheries will lead to pressure on the state agency to develop tournament regulations. A minority of states regulate tournaments fully. Fishery agency staff are involved in tournaments in all states where tournaments are conducted. Tournament data are commonly used for management decisions, mortality studies, age and growth studies, and general population studies. The most commonly cited negative impacts of tournament fishing are conflicts between fishermen and safety hazards. The most commonly cited benefits of tournament fishing are local economic activity, public relations for state fishery agencies, and stimulus of desirable resource use and safe boating practices. A minority of state agencies found a negative impact to the fishery resource or to fishery programs from tournament fishing.

This paper identifies several issues related to competitive fishing as seen from the perspective of state fishery managers. Conflicts between tournament fishermen and nontournament fishermen are common and should be anticipated. Safety hazards should be prevented through advance planning of tournament operations.

Keywords: bass tournaments, impacts, survey, state agencies, conflicts.

Silvey, W., J. Novy, S. Reger, T. Lilies, B. Jacobson, W. Hayes, and J. Warnecke. 1988. Tournament fishing in Arizona, 1986-1987. Statewide Fisheries Investigation Survey of Aquatic Resources Federal Aid Project F-7-R-30.

**Abstract:** This report summarizes data received from voluntary Tournament Fishing Reports submitted by organizations conducting fishing competitions. Large fishing tournaments represent a small portion of the competitive fishing in

Arizona. Most tournament activity is small-scale with high proportion of releases. Despite minimal impact on fishery resources, tournaments should be planned and coordinated to avoid other negative impacts from too much tournament activity at one time or location.

The data provided by the Tournament Fishing Reports will be useful to the planning of competitive fishing arrangements for northern squawfish. Competitive fishing for northern squawfish will not include releases, but other factors of existing fishing competitions will be important to the coordination and planning of a northern squawfish fishing competition.

Keywords: tournament fishing, competitions, impacts.

Talhelm, D.R. 1979. Fisheries dollars and cents. Water Spectrum 11:8-16.

Abstract: The commercial fishery in the Great Lakes was historically of great social and economic importance to the region, but now the sport fishing industry had much greater importance. Economists have estimated that the net social value of Michigan's Great Lakes sport fishery is $250 million compared to $2 million for the commercial fishery. The economic impacts of the two fisheries are about $250 million sport and $20 million commercial. Fisheries have several kinds of values to society, and the purpose of fisheries management is to maximize the aggregate of these values. The concepts of economic rent and angling quality and demand are methods to determine sport fishing values. Bioeconomic simulation models incorporating demand equations can be used to quantify the economic efficiency of salmon enhancement projects to sport fisheries and the relative values of commercial fisheries. The effect of fisheries on local and regional economies is discussed in the context of fishery management decisions, equitable distribution of income among fishery factions, and preserving "ways of life" such as commercial fishing villages. Although sport fishery values are greater than commercial values, the greatest aggregate value is derived by having both, especially when fish species used by the commercial fishery are not game fish. A detailed economic analysis of management alternatives can quantify values and trade-offs and thus help fishery managers make decisions. However, many potential benefits and detriments are not adequately known or quantified.

At present, both sport and commercial fisheries on northern squawfish in the Columbia River are negligible. When and if these fisheries develop, it will be important to quantify their relative values in the context of a bioeconomic model. The effect of the fishery in reducing northern squawfish abundance and the resultant benefits to the salmon fishery would be an important component of such a model.

Keywords: Great Lakes, commercial fisheries, recreational fisheries, evaluation of enhancement projects, trade-offs.

Tschirhart, J. and T.D. Crocker. 1987. Economic valuation of ecosystems. Transactions of the American Fisheries Society 116:469-478.

**Abstract:** This paper demonstrates one way in which an empirically meaningful link between economies and ecosystems might be developed. The natural ecosystem is characterized by inputs, physiological functions, and energy contents of biomass. Humans intervene in the ecosystem by farming, cutting timber, or fishing and thereby directly or indirectly affect all of these features. A model is developed in which human behavior alters the detailed structure of the ecosystem, which in turn alters human behavior. A proposed methodology is presented for valuing ecosystem components which have no direct use value for humans.

This article is relevant to understanding the impacts of a control fishery on northern squawfish, particularly in terms of the multispecies linkages that exist between squawfish and salmonids, suckers, and carp. It has a further bearing on the assessment of the value of an ecosystem component without any current economic value, a characterization which fits squawfish at this time.

**Keywords:** economics, ecosystems, interaction, valuation.

Vanderpool, C.K. 1987. Social impact assessment and fisheries. Transactions of the American Fisheries Society 116:479-485.

**Abstract:** Although social impact assessment methodologies have been developed and applied in other areas of natural resource management, particularly forestry and water resources, they have not been applied in fisheries. Social impact assessments contribute to the process of policy design and management by providing information on the costs and benefits of proposed conservation and management plans. One requirement of a social impact assessment is the construction of a social and cultural data base. Because social impact assessments have not been done in fisheries these data bases have not been built. Social and cultural data are useful to assess the distributional consequences of a particular fishery management plan. What is desirable in resource management is an integrated assessment and evaluation process which provides a coordinated system for determining the costs and benefits of policy implementation and project outcomes. Good social impact assessments in the fishery would require an understanding of the role of assessment in natural resource development as well as the development of good comparative data bases on social factors related to fishing.

The types of social and cultural data described in this article would be crucial to an understanding to the impact of fishery development on Columbia River northern squawfish. A social impact assessment would provide valuable information on the likely impact of a particular development approach or allocation scheme that might otherwise be ignored.

**Keywords:** fisheries, social impact assessment, social, cultural, allocation, fishery development.

Whitworth, W.E. 1984. Bass tournament fishing in Texas: status report. Texas Parks and Wildlife Department, Austin, Texas. 89pp.

**Abstract:** Because bass tournament fishing is an increasingly popular sport in Texas and is conducted by organized groups of skilled interested fishermen, the Texas Parks and Wildlife Department (TPWD) is interested in using tournament data as a source of population information on bass. The TWPD developed a voluntary program to encourage bass clubs to report data from their tournaments. By 1984 the TPWD had developed a large database containing information on over 5,000 tournaments. This database provides information on population trends and quality of fishing experiences and contributes to management decisions affecting bass populations.

Data from northern squawfish tournaments can also be used in the analysis of population trends. This population information will assist in management decisions.

**Keywords:** fishing tournaments, voluntary reporting, fisheries database, population trends, bass management.

Wilson, J. 1982. The economical management of multispecies fisheries. Land Economics 58(4):417-434.

**Abstract:** This paper is concerned with developing an economic analysis appropriate to the biological and social characteristics of variable multispecies systems. The paper is built on three fundamental ideas: 1) limitations of knowledge and uncontrolled variation in fisheries constrain the range of economically feasible management options; 2) social costs of rule making and enforcement are high in highly variable environments; 3) efficiency in variable environments is more closely related to adaptive individual learning behavior than to input cost minimization. These ideas are developed in the context of an institutional theory about the growth of collective mechanisms for the solution of potentially degenerative social situations.

The accepted economic theory of fisheries is misleading in that it tends to direct analysis away from a consideration of many reasonable and economical non-property rights policy alternatives. Consideration of "complicating factors"--

multiple species, variability, patchiness, search and information costs--tends to lead to the conclusion that the social costs of unregulated fishing are less than traditional economic theory would suggest. These complicating factors indicate higher social costs associated with attempts to regulate. These two effects tend to limit the range of economically feasible management options and appear to create a strong preference for very simple systems of management rules.

The management of a fishery on northern squawfish as a multispecies fishery would suggest an application for several of the ideas outlined in this paper. Marine fisheries offer many examples of multispecies fisheries that are managed as concurrent single-species systems, with the associated social costs. This paper points out some of the costs of attempting to "over manage," or fine-tune, a multispecies fishing system.

Keywords: multispecies fisheries, management, efficiency, adaptive learning, social costs.

Yarbrough, C.J. 1987. Using political theory in fisheries management. Transactions of the American Fisheries Society 116:532-536.

Abstract: This paper explores three areas of political theory and their implications for fishery management. First, democratic theory states that ultimate political power in a society is vested in the people. This includes a belief in local autonomy and a belief that public opinion has ethical status. Democratic theory confronts fishery managers with the need to respect the tradition of localism and generate public support for programs. Second, political value theory attempts to understand values held by the public. Core values held by the public are persistent. This means that managers must justify programs in terms of consistency with basic public values. Third, political structure theory looks at the influence of formal and informal government, economic, and social structures on the acceptance and success of public programs. Structure theory describes the limits of political action as well as the possibilities. This theory tells managers that the structure of existing governmental and economic institutions works against broad management initiatives, against taking an ecosystem approach to management. The author argues that political theory provides insight to fishery managers about what is possible as well as what is not possible.

This article offers insights into the process of fishery management, both in terms of pathologies in our existing management process and in terms of possibilities for change and limits to those possibilities. This is a helpful review of process that would provide guidance in the formation of new policy for fishery development.

Keywords: resource management, political theory, democratic principles, values, institutional structure.

## APPENDIX B-2.

Preliminary Results of Tests for Contaminants in Northern Squawfish

1. FDA Foodstuff Action Levels for Selected Contaminants

2. Organic Contaminants

3. Heavy Metal Contaminants

Table B-5. FDA Foodstuff Action Levels for Selected Contaminants.

| | FDA Foodstuff Action Level (ppm) |
|---|---|
| **Chlorinated Pesticides and PCB's** | |
| alpha-BHC | 0.3* |
| beta-BHC | 0.3' |
| Lindane | 0.5** |
| Heptachlor | 0.3 |
| Heptachlor epoxide | 0.3 |
| Aldrin | 0.3*** |
| Dieldrin | |
| p,p' DDE | 5.0 |
| p,p' DDD | 5.0 |
| p,p' DDT | 5.0 |
| p,p' Methoxychlor | 5.0 |
| Chlordane | 0.3 |
| PCB Group 1 | 2.0 |
| PCB Group 2 | 2.0 |
| PCB Group 3 | 2.0 |
| PCB Group 4 | 2.0 |
| PCB Group 5 | 2.0 |
| **Heavy Metals** | |
| Mercury | 1.0 |
| Arsenic | **** |
| Cadmium | **** |
| Chromium | **** |
| Copper | **** |
| Lead | **** |
| Zinc | **** |

* Level established for rabbit meat. No level established for fish.
**
Level established for eggs. No level established for fish.
*** Level established for sum of Dieldrin and Aldrin values.
**** No FDA Action level established.

## B-2.2. Preliminary Results of Tests for Organic Contaminants in Northern Squawfish

## B-2.1. FDA Foodstuff Action Levels for Selected Contaminants

DEPARTMENT OF ENVIRONMENTAL QUALITY LABORATORIES



Analytical Records Report

PRELIMINARY report, results are NOT conclusive. Printed by

CASE NAME: 890371 JOHN DAY RESERVOIR
SUBMITTER: Vigg, Steve
FUND CODE: 3250 205J(5)- Nonpoint Source

| ITEM # | RESULT | UNITS | TEST |
|---|---|---|---|
| 001 Small Fish, Edible portion 05/03/89 | | | |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |
| 002 Large Fish, Edible portion 05/03/89 | | | |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |
| 003 Small Fish, Liver 05/03/89 | | | |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |
| 004 Large Fish, Liver 05/03/89 | | | |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |

RECEIVED
JUN 16 1989
Water Quality Division
Dept. of Environmental Quality

Department of Environmental Quality
Laboratories and Applied Research
Organic Section

6C
CHLORINATED PESTICIDES AND PCBs
Complies with EPA NPDES Method 608 and
RCRA Method 8080

Date: 1 June 1989

Lab #: 890371
Sample: 1-FISH
Item #: 1 59

| Amount MG/KG | Parameter | CAS Registry Number |
|---|---|---|
| <0.003 | alpha-BHC | 319846 |
| <0.003 | beta-BHC | 319857 |
| <0.003 | Lindane | 58899 |
| <0.003 | Heptachlor | 76448 |
| <0.003 | Aldrin | 309002 |
| (9.903 | Heptachlor epoxide | 1024573 |
| <0.003 | p,p' DDE | 72559 |
| <0.003 | Endrin | 72208 |
| <0.003 | p,p'DDD | 72548 |
| <0.003 | p,p'DDT | 50293 |
| <0.003 | p,p'Methoxychlor | 72435 |
| 0.011 | Dieldrin | 60571 |
| <0.003 | Chlordane | 57749 |
| <0.012 | PCB Group 1 | 11104282 |
| <0.006 | PCB Group 2 | 11141165 |
| <0.003 | PCB Group 3 | 53469219 |
| <0.003 | PCB Group 4 | 11097691 |
| <0.003 | PCB Group 5 | 11595625 |
| ND | Total PCB | |

PC3 Group 1 includes PCB 1221 and is calculated as 1221.
PCB Group 2 includes PCB 1232 and in s calculated as 1232.
PCB Group 3 includes PCB'S 1016, 1242 and 1248 and is calculated as 1242.
PCB Group 4 includes PCB 1254 and is calculated as 1254.
PCB Group 5 includes PCB's 1260 and 1262 and is calculated as 1264.

MD No PCB's observed above indicated detection limit.

Department of Environmental Quality
Laboratories and Applied Research
Organic Section

PRELIMINARY
DATE:

GC
CHLORINATED PESTICIDES Am PCBs
Complies with EPA NPDES Method 648 and
RCRA Method 8484

Date: 1 June 1989

Lab #: 894371
Sample: 2-FISH
Item #: 2

550

| Amount MG/KG | Parameter | CAS Registry Number |
|---|---|---|
| <0.003 | alpha-BHC | 319846 |
| <0.003 | beta-BHC | 319857 |
| <0.003 | Lindane | 58899 |
| <0.003 | Heptachlor | 76448 |
| <0.003 | Aldria | 309002 |
| <0.003 | Heptachlor epoxide | 1024573 |
| 0.073 | p,p' DDE | 72559 |
| <0.003 | Endrin | 72208 |
| 0.007 | p,p'DDD | 72548 |
| <0.003 | p,p'DDT | a0293 |
| <0.003 | p,p'Methoxychlor | 72435 |
| <0.003 | Dieldrin | 60571 |
| <0.003 | Chlordane | 57749 |
| <0.012 | PCB Group 1 | 11104282 |
| <0.006 | PC8 Group 2 | 11141165 |
| <0.003 | PC8 Group 3 | 53469219 |
| 0.113 | PCB Group 4 | 11097691 |
| 0.041 | PCB Group 5 | 11496625 |
| 0.154 | Total PCB | |

PC8 Group 1 includes PCB 1221 and is calculated as 1221.
PC3 Group 2 includes PCB 1232 and in s calculated as 1232.
PC8 Group 3 includes PCB'S 1416, 1242 and 1248 and is calculated as 1242.
PCB Group 4 includes PCB 1254 and is calculated as 1254.
PCB Group 5 includes PCB's 1268 and 1262 and is calculated as 1260.

ND No PCB's observed above indicated detection lirit.

Department of Environmental Quality
Laboratories and Applied Research
Organic Section

PRELIMINARY
DATE:

GC
CHLORINATED PESTICIDES AND PCBs
Complies with EPA NPDES Method 608 and
RCRA Method 8080

Date: 1 June 1989

Lab #: 890371
Sample: REDFISH
Item #: 3

550

| Amount MG/KG | Parameter | CAS Registry Number |
|---|---|---|
| <0.003 | alpha-BHC | 319846 |
| <0.003 | beta-BHC | 319857 |
| <0.003 | Lindane | 58899 |
| <0.003 | Heptachlor | 76448 |
| 0.03 | Aldrin | 309002 |
| <0.003 | Heptachlor epoxide | 1024573 |
| 0.785 | p,p' DDE | 72559 |
| <0.003 | Endrin | 72208 |
| 1.248 | p,p'DDD | 72548 |
| <0.003 | p,p'DDT | 50293 |
| 0.004 | p,p'Methoxychlor | 72435 |
| 0.037 | Dieldrin | 60571 |
| <0.003 | Chlordane | 57749 |
| <0.012 | PCB Group I | 11104282 |
| <0.006 | PCB Group 2 | 11141165 |
| <0.003 | PCB Group 3 | 53469219 |
| <0.003 | PCB Group 4 | 11097691 |
| <0.003 | PCB Group 5 | 11096825 |
| ND | Total PCB | |

PCB Group 1 includes PCB 1221 and is calculated as 1221.
PCB Group 2 includes PCB 1232 and is calculated as 1232.
PCB Group 3 includes PCB'S 1016, 1242 and 1248 and is calculated as 1242.
PCB Group 4 includes PCB 1254 and is calculated as 1254.
PCB Group 5 includes PCB's 1260 and 1262 and is calculated as 1260.

ND No PCB's observed above indicated detection limit.

PRELIMINARY
DATE:

Department of Environmental Quality
Laboratories and Applied Research
Organic Section

6C
CHLORINATED PESTICIDES AND PCBs
Complies with EPA NPDES Method 608 and
RCRA Method 8080

Date: 1 June 1989

Lab #: 890371
Sample: BLUFISH 550
Item #: 4

| Amount MG/KG | Parameter | CAS Registry Number |
|---|---|---|
| 0.343 | alpha-BHC | 319846 |
| 0.543 | beta-BHC | 319857 |
| <0.003 | Lindane | 58899 |
| 4.33 | Heptachlor | 76446 |
| <0.003 | Aldrin | 349862 |
| <0.003 | Heptachlor epoxide | 1024573 |
| 3.13 | p,p' DDE | 72559 |
| 1.74 | Endrin | 72208 |
| 0.99 | p,p'DDD | 72548 |
| <0.003 | p,p'DDT | 50293 |
| <0.003 | p,p'Methoxychlor | 72435 |
| <0.003 | Dieldrin | 60571 |
| <0.003 | Chlordane | 57749 |
| <0.012 | PCB Group 1 | 11104282 |
| <0.006 | PCB Group 2 | 11141165 |
| <0.003 | PCB Group 3 | 53469219 |
| <0.003 | PCB Group 4 | 11097691 |
| <0.003 | PCB Group 5 | 11096625 |
| ND | Total PCB | |

PCB Group 1 includes PCB 1221 and is calculated as 1221.
PCB Group 2 includes PCB 1232 and is calculated as 1232.
PCB Group 3 includes PCB'S 1016, 1242 and 1248 and is calculated as 1242.
PCB Group 4 includes PCB 1254 and is calculated as 1254.
PCB Group 5 includes PCB's 1260 and 1262 and is calculated as 1260.

ND No PCB's observed above indicated detection limit.

PRELIMINARY
DATE: ____

FATS / LIPIDS

| LAB # | ID # | FISH TYPE | ppm * | % * |
|---|---|---|---|---|
| 890371-3250 | 1-Fish | Squawfish | 12555 | 1.256 |
| | 2-Fish | Squawfish | 5180 | 0.518 |

* wet method
(wet weight basis)

### B-2.3. Preliminary Results of Tests for Heavy Metal Contaminants in Northern Squawfish

# DEPARTMENT OF ENVIRONMENTAL QUALITY LABORATORIES
## Analytical Records Report



WEDNESDAY OCTOBER 4th, 1989

**CASE NAME:** 890371 JOHN DAY RESERVOIR
**SUBMITTER:** Gates, Richard F. **COLLECTOR:** Vigg, Steve
**FUND CODE:** 3250 205J(5)- Nonpoint Source

| ITEM # | RESULT | UNITS | TEST |
|---|---|---|---|
| **001 Small Fish, Edible portion** 05/03/89 | | | |
| | 6.98 | mg/Kg dry | Mercury, Fish Tissue |
| | <0.15 | mg/Kg drq | Arsenic, Fish Tissue |
| | <0.04 | mg/Kg dry | Cadmium, Fish Tissue |
| | <0.15 | mg/Kg dry | Chromium, Fish Tissue |
| | 1.1 | mg/Kg dry | Copper, Fish Tissue |
| | <0.15 | mg/Kg dry | Lead, Fish Tissue |
| | 23.3 | % | % SOLIDS, Fish Tissue |
| | 22 | mg/Kg dry | Zinc, Fish Tissue |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |
| **002 Large Fish, Edible portion** 05/03/89 | | | |
| | 3.20 | mg/Kg dry | Mercury, Fish Tissue |
| | <0.15 | mg/Kg dry | Arsenic, Fish Tissue |
| | <0.04 | mg/Kg dry | Cadmium, Fish Tissue |
| | <0.15 | mg/Kg dry | Chromium, Fish Tissue |
| | 1.2 | mg/Kg dry | Copper, Fish Tissue |
| | <0.15 | mg 'Kg dry | Lead, fish Tissue |
| | 23.0 | % | % SOLIDS, Fish Tissue |
| | 19 | mg/Kg dry | Zinc, Fish Tissue |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |
| **003 Small Fish, Liver** 05/03/89 | | | |
| | ATTACHed | | chlorinated Pesticides in Tissues, Fish Tissue |
| **004 Large Fish, Liver** 05/03/89 | | | |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |

# REPORT C
# EVALUATION OF HARVESTING TECHNOLOGY FOR POTENTIAL NORTHERN SQUAWFISH COMMERCIAL FISHERIES IN COLUMBIA RIVER RESERVOIRS

Prepared by

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## CONTENTS

## ACKNOWLEDGMENTS

We thank the operators of the Umatilla marina for providing us boat and net pen moorage and other facilities and services at very reasonable rates. We thank Mr. Brad Eby and others of the U.S. Army Corps of Engineers at McNary Dam for providing us smolt collector mortalities for bait. Thanks also to Mr. Paul Wagner, Washington Department of Fisheries biologist at McNary Dam, for help in smolt mortality collections.

## ABSTRACT

After literature review and discussion with knowledgeable experts, we chose four small-boat gear types to test in the field for their applicability to commercial harvest of northern squawfish, *Ptychocheilus oregonensis*, in Columbia River reservoirs: Purse seine, longline, gillnet, and baited pot.

Our sampling was divided in two sampling seasons. During the summer sampling period, from April to August 1989, we focused on the efficiency of longlines and gillnets as commercial fishing gear for capturing northern squawfish. We fished this gear in five areas of the John Day reservoir. A total of 167 one-plus hour sets of stationary, sunken gillnets yielded 122 northern squawfish. The nets were of variable mesh and measured 150x10 ft. Northern squawfish composed 14% of the sunken gillnet catches of all species. Longlining with monofilament groundline, 3/0 stainless hooks and salmonid smolts for bait was the most effective method for capturing northern squawfish. A total of 525 northern squawfish was caught on 115 sets of 25-150 baited hooks. Catches of one northern squawfish per 4 or 5 hooks set were the best rates achieved; these were made near McNary Dam. Northern squawfish composed 72% of the catches of all species. White sturgeon, *Acipenser transmontanus*, and channel catfish, *Ictalurus punctatus*, were caught frequently on longlines and were usually alive and viable at release.

Limited purse-seining with a 350'x25' deep seine was very ineffectual except in the McNary Dam spillway during the month of July where catches averaged five northern squawfish per set; northern squawfish composed 44% of the purse-seine catches (in numbers) of all species. Baited pots and floating gillnets (set and drift) were relatively ineffectual.

During the fall sampling period, from September through November, effort was focused on determining the effect of bait type, hook type, and depth of bait on the catching efficiency of the longline. 82 longline sets were made using various baits and hooks. American shad yearlings had the highest catch rate averaging one northern squawfish for every 17.33 hooks set. The Kahle horizontal hook (English bait hook) proved to be the most efficient hook type.

Northern squawfish tend to be distributed throughout the water column, at least during this time of the year, and therefore longlines should be fished vertically from the surface to the bottom.

Both longline and purse seine catches declined in the fall. A lake trap was fished for 48 hours and caught only 8 northern squawfish. Gillnet catches did increase slightly but fishing effort for this gear was very low.

# INTRODUCTION

Northern squawfish, *Ptychocheilus oregonensis, in the* Columbia River are of limited recreational use and currently of no commercial value. They are, however, the major predator of outmigrating salmon in the John Day reservoir and probably throughout the Columbia River; research in the John Day reservoir demonstrated that northern squawfish consume a sufficiently high proportion of the salmonid outmigrants to probably cause significant reduction in the numbers of returning adult salmon and steelhead (Poe and Rieman 1988). Model studies indicated that a sustained exploitation rate of 10-20% annually in the John Day reservoir would reduce the population and average size of northern squawfish sufficiently to cause a major reduction in salmonid losses (Rieman and Beamesderfer 1988). A variety of fishing methods could be employed to achieve this level of harvest. Among them, one or several should be found which (1) would not incidentally kill valued fish such as salmonids, sturgeon, catfish, bass, or walleye; (2) could be inexpensively employed by commercial fishermen using the type of small vessels already in use for salmon, sturgeon, and shad fishing on the Columbia; and (3) would have sufficiently high catch rates on northern squawfish to yield an annual exploitation rate of approximately 20%.

Obviously item (3) will not happen unless there is sufficient economic return from the catch. This can occur from either of two sources: (1) Development of commercial markets for northern squawfish, or (2) establishment of a bounty or subsidy by a public agency. Establishing potential commercial outlets and setting a correct level of bounty are the objectives of a sister research project by Oregon State University (OSU) ("Economic Feasibility of Commercial and/or Bounty Fisheries for Northern Squawfish").

The goal of the multiple-agency predator-prey research programs on the Columbia River, of which the Harvest Technology project is one phase, is to increase adult salmonid returns by reducing in-river predation on outmigrants. One aspect of active management of predation-caused losses of juvenile salmonids would be the development of a fishery on northern squawfish in order to reduce their numbers. The goal of the Harvest Technology evaluation (Addendum to Statement of Work, Project 82-012) is to provide further detail to Objective 3, Task 3.2, Activity 3.213--specifically, the component dealing with harvest technology. The specific objectives are to:

(1) Evaluate commercial harvesting technology of various fishing methodologies for northern squawfish in Columbia River reservoirs.

(2) Field test the effectiveness of identified commercial harvesting systems, i.e., fishing methods, holding facilities, and transportation.

(3) Integrate the "Harvesting Technology" research with other components of the study, i.e., coordination to ensure research and data collection are designed to support the "Economic Feasibility" study.

(4) Assess potential for incidental catch mortality of valued species for each of the gear types tested for use in northern squawfish harvesting.

The "Harvesting Technology" project period is 1 February 1989 - 31 March 1990. The report covers activities concerned with literature search, gear selection, gear design and construction, field testing of gear, data acquisition, holding mortality of incidentally caught species, and gear efficiency comparisons.

The project began with a two-month (March-April) information search which included literature review and personal contacts with biologists, fishermen, and fishing gear manufacturers who had experience with commercial or control fisheries on non-game freshwater species (Mathews et al., 1990, Appendix C-1). Based on this information, gear types were selected for field testing. Gear equipment was purchased, and two Boston Whalers, open outboard-powered boats, were appropriately outfitted. One was a 22-footer with a 200-hp engine provided by Oregon Department of Fish and Wildlife to our project; the other was a 20-footer with a 165-hp engine chartered from the University of Washington. A field station which included housing, storage and working facilities was leased in Umatilla, OR.

Preliminary fishing activities commenced in April 1989. For the period 15 May-12 August, a pre-set spatial/temporal pattern of fishing and biological sampling in the John Day reservoir was followed, except for minor modifications required by weather and other unforeseen events.

During our project we evaluated only commercial fishing gear types as control alternatives. Other techniques to reduce squawfish predation on salmonids have been researched and could be utilized in conjunction with a commercial fishery (Jeppson and Platts 1959; LeMier and Mathews 1962; Hamilton et al. 1970; Poe et al. 1988).

A commercial fishery has several advantages. It is well-known that virtually any stock of fish can be reduced substantially by commercial fishing if economic incentives are high. A commercial fishery could use an existing pool of skilled manpower and boats at times when not alternatively employed. A commercial fishery might be easier to regulate and evaluate than a sport fishery, which is another control alternative, because fewer but more efficient individuals would be involved with the former. If a market can be developed for northern squawfish, there is potential for economically self-sustaining control. Additionally, a potential resource would then be utilized.

If a commercial fishery is to develop, potential fishermen need to know expected CPUE by location and season, investment and operation costs of suitable gear and equipment, and various operational constraints such as weather and water conditions and availability of ancillary facilities like moorage and launching sites. Our project is intended to provide such information. Additionally, fishermen need to know expected prices, product forms, and handling and delivery requirements. Such data are products of the sister study by OSU.

The fishery management agencies have several concerns to face in developing a commercial northern squawfish fishery. How can squawfish be harvested with least impact on other species? Can squawfish be commercially harvested in a manner that does not interfere significantly with other users of Columbia River water resources? Does squawfish harvesting effectively reduce salmonid predation? And finally, are there any adverse ecological effects with reduction of squawfish populations? Informational needs for certain aspects of these questions are also to be provided by our "Harvest Technology" project.

# METHODS

## Selection of Fishing Gear for Testing

Our main criteria for gear selection were (1) that it be adaptable to commercial vessels of the sizes and types generally used in the Columbia River and adjacent regions, and (2) that it be suitable to the physical environment of Columbia River reservoirs. Columbia River fishing vessels tend to be less than 30', are outboard or inboard/outboard powered, and may be open (no cabin). We therefore considered the following gear types as potential candidates for field testing: Purse seine, baited longlines, beach seine, baited pots, set gillnet, drift gillnet, and trap net.

Table C-1 summarizes our selection process. We developed a subjective scoring system (1-3 points), ranking each gear type according to the 10 criteria shown. A high-ranking score indicates relatively high degree of potential suitability.

Purse seining is relatively untested, particularly away from dam areas. It can be done from small boats, but usually two boats are needed. Specific modifications must be made to a boat, but these might not be too costly if a boat already had a net reel and hydraulic system. Product quality should be excellent since the fish are alive at capture; live capture also allows the potential of releasing other species unharmed. Purse seining would be difficult in high winds which are common in Columbia River reservoirs. Two or three crewmen are required, but seining, as opposed to stationary gear types, would not have gear-tending requirements, nor would conflict due to entanglement with sport fishermen or other vessels be a likely problem. Purse seining is limited to depths greater than the net depth.

Baited long-lines have not been previously tested for squawfish and are easily and cheaply adaptable to boats of any size capable of handling the water conditions. Longlines can be fished at any depth, in most weather, and in all current conditions, except perhaps the turbulent boils immediately below the dam spillways and power houses. Most fish would be alive at capture, and therefore of good quality. Incidental mortality of desirable species from hooking and handling is the main potential problem. Also, longlines and associated buoy lines have potential for entanglement conflicts with other boats and fishermen.

Beach seining is a simple and inexpensive method easily adapted to small boats. It has advantages similar to purse seining: Live product, ease of release of incidental species, and lack of tending requirements. However, suitable beach seining sites are limited and previous researchers reported very low catch rates of large (>250mm) squawfish using beach seines.

Table C-l. Criteria for choice of test gear types:
Most advantageous = 3, least advantageous = 1.

| | Purse seine | Baited longline | Beach seine | Baited pots | Set gillnet | Drift gillnet | Trap net |
|---|---|---|---|---|---|---|---|
| Adaptable to present boats | 2 | 3 | 3 | 2 | 3 | 3 | 2 |
| Fishable in most areas | 1 | 3 | 1 | 3 | 3 | 1 | 1 |
| Relatively untested | 3 | 3 | 1.5 | 3 | 1 | 2 | 1 |
| Opinions of others | 2 | 3 | 1 | 1.5 | 1.5 | 1 | 2 |
| High quality of live product | 3 | 2 | 2 | 2 | 1.5 | 2 | 3 |
| Low incidental catch | 3 | 2 | 2 | 2 | 1 | 1 | 1 |
| Ease of handling | 1.5 | 3 | 2 | 2 | 3 | 2 | 1 |
| Suitable in bad weather | 1 | 3 | 1 | 3 | 3 | 2 | 2 |
| Low investment | 2 | 3 | 3 | 2 | 2 | 2 | 1 |
| Tending requirements | 3 | 2 | 3 | 1 | 1 | 3 | 1 |
| Total | 21.5 | 27 | 19.5 | 21.5 | 20 | 19 | 15 |

Baited pots have been little tested and could be fished virtually anywhere. They could also be left out in bad weather and would continue to fish. They would probably have to be deployed for considerable time periods (perhaps overnight), which might reduce product quality or even induce mortality of northern squawfish and other species entrapped. Pots are fairly expensive items and untended ones might entice theft.

Gillnetting is perhaps the most commonly used and productive small-boat gear type in the world. Gillnetting is inexpensively adaptable to small boats. Stationary gillnets can be set many places except in heavy current while drift gillnets can be employed in fast current, but would probably not be efficient out of current. Gillnets are easy to handle and fishable under most weather conditions. Stationary nets may require tending and have potential for entanglement conflict. Since fish captured by gillnets are often dead at capture, product quality of target species may be a problem with gillnets, and there could be adverse impacts on populations of incidentally caught species. Set gillnets have been used extensively for northern squawfish capture in the Columbia River and elsewhere, and abundant data exist on catch rates. Drift gillnets have been less tested.

Trapping is another form of capture that yields a live, potentially high quality target product with good potential for unharmed release of incidentally caught species. Two types of traps have been extensively investigated on the Columbia River, the Merwin trap and the lake trap. The Merwin trap, a modified version of a floating salmon trap, was developed by the Washington Department of Fisheries (Hamilton et al. 1970). A Merwin trap is a large, cumbersome structure with usually a long lead and requiring specialized vessels and considerable manpower to move about and set. Tending and maintenance requirements are high. Merwin traps have been shown to be very effective on northern squawfish in certain situations such as spring (presumably spawning) migration in weather-protected sites. Unless the physical support and float systems were stronger than those previously tested, these traps could not be used effectively along unprotected shorelines or areas of even moderate current.

The lake trap (Nigro et al. 1985) is smaller than the Merwin trap and readily adaptable to small-boat use. Like the Merwin trap, the lake trap cannot be fished in much current and requires considerable cleaning and tending. Furthermore, this gear type was tested for several years in the John Day reservoir during the research efforts involved in assessing northern squawfish and other predator populations. Low catch rates [averaging three squawfish or less per trap haul over extensive tests (Nigro et al. 1985, 1984)] and relatively high handling requirements indicated this would probably be an inefficient commercial gear type.

With these considerations in mind, we selected purse-seining and long-lining as potentially effective, relatively untested gear types that should be tested most extensively. We also felt pots should be tested on a spot-check basis. Also, we added gillnets -- both set and drift -- to our repertoire for field testing. We were fairly certain that incidental catch mortality during much of the year would often cause such gear to be inappropriate. However, gillnets have been relatively untested for northern squawfish in the winter, and there were circumstances cited in the literature in which northern squawfish were efficiently captured by such gear (Foerster and Ricker 1941; U.S. Fish and Wildlife Service 1957). Also, gillnetting indices of northern squawfish abundance by age-class were previously established for the John Day reservoir and the cooperating agencies (University of Washington, Oregon Department of Fish and Wildlife, and U.S. Fish and Wildlife Service) desired to maintain continuity in population assessment methodology during the present sampling season. Thus, the use of gillnets was for biological monitoring purposes (Vigg and Burley 1990) as well as for assessing this gear type for commercial fishery potential.

Due to numerous factors, we effectively had two sampling seasons: April through August, or summer sampling season, and September through November, the fall sampling season. During summer sampling we set out to determine the most efficient gear for capturing northern squawfish, in terms of the least incidental catch and highest squawfish catch rates. In the fall we emphasized improvement on the longline gear and the effects of bait type, hook type, and fishing depth on fishing success.

## Description of Purse Seine Gear

Seine length was 350 ft (107 m). Hung depth of the mesh was 25 ft (7.6 m), but the purse rings hung down an additional 2 ft (0.6 m), so the total depth of the gear was 27 ft (8.2 m). Web was #12 knotted twine, 2.5 in. (6.35 cm) stretch mesh in all but the 35 ft (10.7) bunt which was 2 in. (5.08 cm) stretch mesh. Lead-line was 150 lbs (68 kg) per 100 fathoms (183 m). Corks were placed every foot (30.5 cm), except in the bunt where they were spaced 6 in. (15.2 cm) apart. Purse line was 7/16-in. (1.1 cm) diameter woven nylon. Initially, the net was hung with 50 purse rings spaced every 7 ft (2.1 m), but this was an excessive number and caused handling difficulty. We therefore removed half, leaving 25 rings at 14 ft (4.3 m) spacing.

Special equipment to fish the seine is shown in Figure C-1. This included a 3 ft (91.4 cm) wide by 3.5 ft (106.7 cm) diameter chain-driven drum; a net level-wind mechanism operated intermittently by a hand control valve; a set of bow fairleads for net retrieval; a boom and block arrangement for pursing and suspending purse rings during retrieval; a 5-in. (12.7 cm)

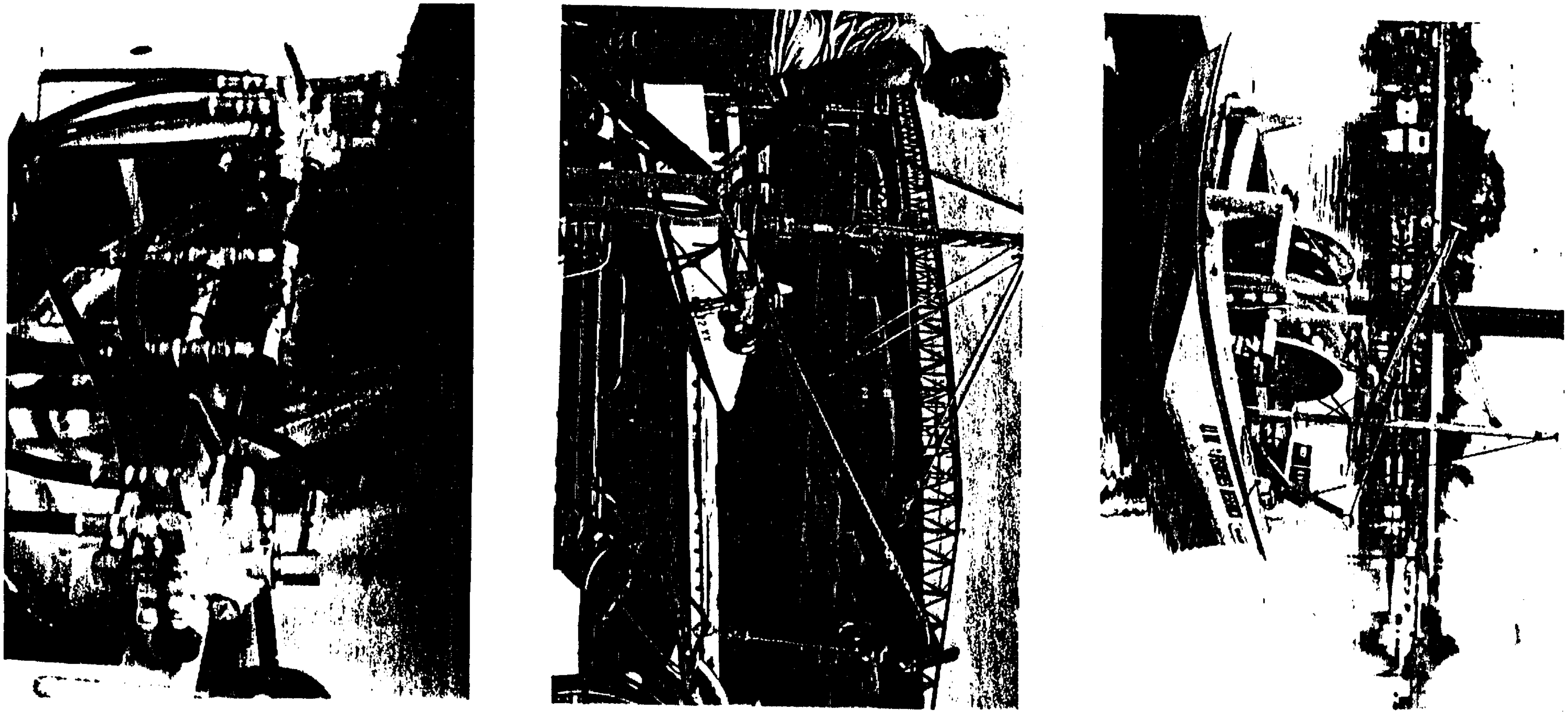


Figure C-1. Purse seine equipment: Drum, fairleads, boom and block, "hairpin", hydraulic valves.

gypsy winch for purse line hauling; a gasoline-driven hydraulic power pack (8 hp gas motor, 6 gpm pump); hydraulic lines (0.5 in., 1.3 cm) and valves; and a "hairpin" for suspending purse rings during retrieval.

This equipment was mounted on the 20 ft (6.1 m) UW Boston Whaler. Two separate vessels were used as seine skiffs during trials: A 14 ft (4.3 m) aluminum skiff with 15 hp outboard, and the 22 ft (6.7 m) ODF&W Whaler with a 200 hp outboard motor. Neither vessel was well suited because they lacked a suitable midship towing bar. The Whaler was more suitable because it could tow from the bow in reverse. This was satisfactory, particularly since it allowed the skiff operator to view the operation without having to turn around.

## Description of Longline Gear

The mainline, gangions, winch, and fairlead are shown in Figure C-2. The longline system consisted of 1.5 mm diameter (250 lb, 113.4 kg test) monofilament groundline with brass-bead stops every meter, nylon gangion snaps with push-on attachment design, and 12 in. (30.5 cm) long monofilament gangions with hooks of various types and sizes. Anchors of 15 lb (6.8 kg) lead-filled steel pipe and A2 Polyform buoys were placed at both ends of a section of groundline. Smaller anchors (5 lb, 2.3 kg sash weights) and floats were attached by halibut snaps to the groundline alternately at various spacing distances to suspend the baited hooks at varying depths off the bottom. A normal set was 50-75 hooks on 300-400 ft (91-122 m) of groundline.

We tested two setting methods: A hand-operated winch, and a hydraulically operated drum. The hand-operated method was the best, since the boat operator could feel the tension on the groundline through the pressure on the winch handle during setting and retrieving, and could adjust boat speed accordingly. Keeping proper tension in the groundline was an important aid to the person snapping or unsnapping the hooks. Hydraulically or electrically operated systems (or an alternate hand reel system) might ultimately be most efficient, but proper location of drum, fairlead, and boat controls is crucial to a smooth operation. In our operation, the reel and fairlead were so arranged that gear was set in reverse and retrieved in forward over the bow. Two people were needed to operate our gear, but more efficiently designed systems could be operated by one person.

Hooks were normally 3/0 stainless steel "steelhead/salmon" type (Figure C-3). This hook was easiest to bait and unbait and stayed sharp well. Alternative hook styles tested were 3/0

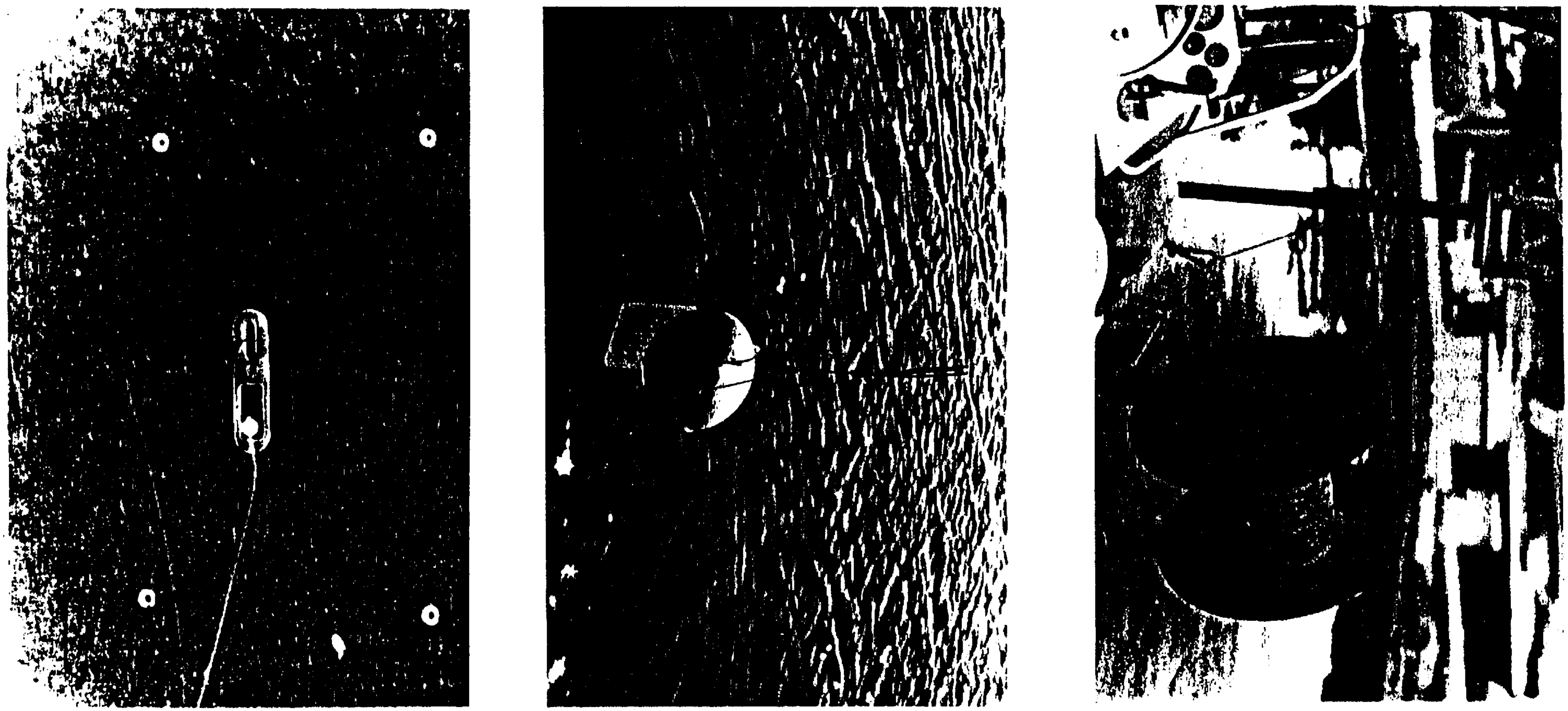


Figure C-2. Longline equipment: Reel, fairlead, groundline, gangion snap.

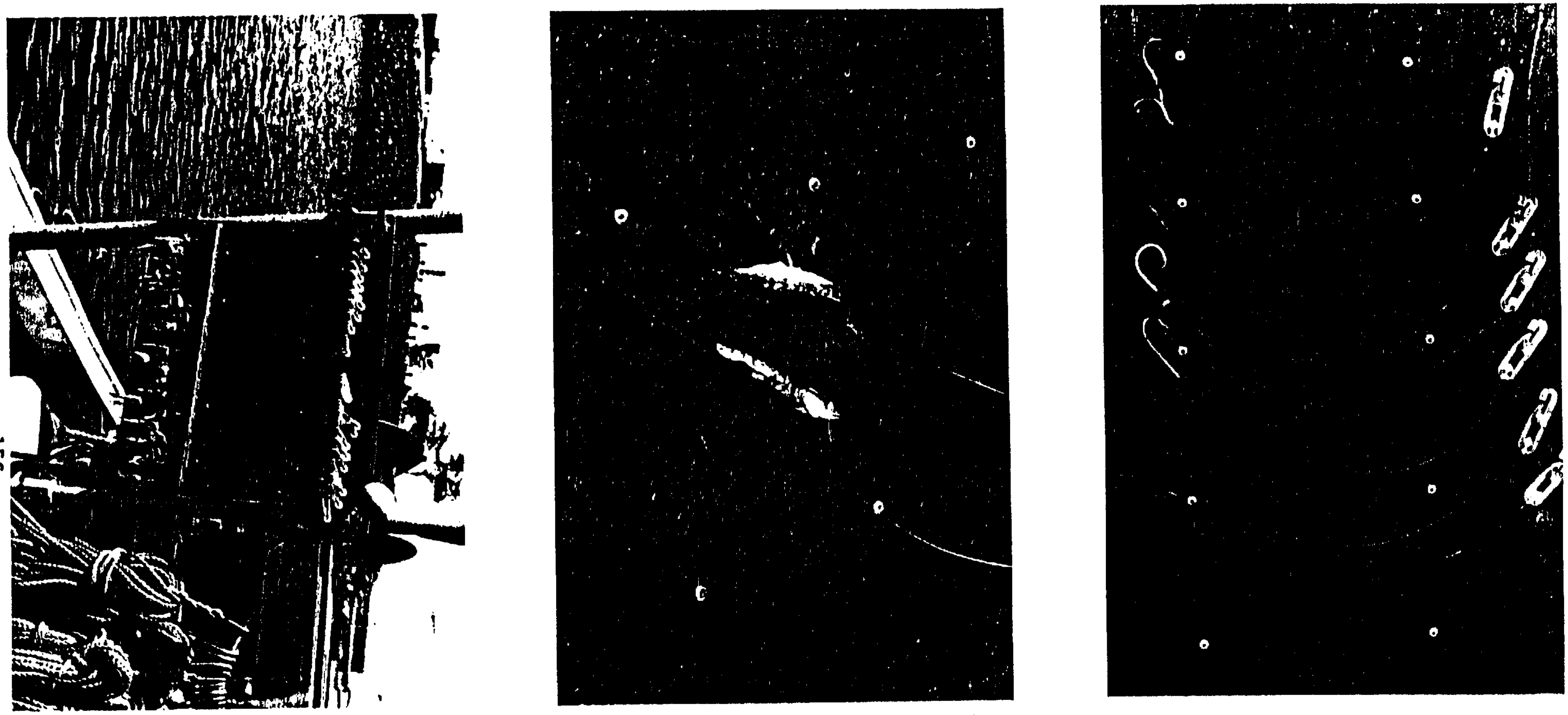


Figure C-3. Longline gear: Hooks, baits, hookboard.

steel Kahle horizontal hook (English bait hook), 3/0 tinned circle hook, and 3/0 tinned "J" hook. A double hook arrangement was also tried by tying two steelhead/salmon hooks on a single gangion approximately one inch apart.

Baits were usually whole salmonid smolts (2.5"-4", 6.4-10.2 cm) or cut chunks of salmonid smolts. The smolts were obtained from the McNary Dam smolt collector operated by the U.S. Army Corps of Engineers. Dead smolts are collected regularly on the drift screens throughout the summer. We used fresh, frozen, and salted baits. Other baits tested during the summer were trout-perch, cottids, salmon eggs, and cut chunks of squawfish and suckers. During the fall months, American shad were beach seined and used fresh and salted. Any crayfish caught in the baited pots were also cut up and used for bait. Other alternative baits tested were nightcrawlers and salted herring.

Gangions of various breaking strengths were tested, and 30 lb (13.6 kg) test seemed most satisfactory. Materials of lighter test became snarled and twisted. Gangions of 30 lb (13.6 kg) test usually broke when large sturgeon or catfish were hooked. Large fish which could not break loose tended to foul the gear. The 30 lb (13.6 kg) gangions seldom became snarled or twisted.

The unique gangion snap had a simple but effective swivel mechanism, an important feature which prevented gangions from twisting on themselves or around the groundline. The bitter end of the gangion fastened through a small hole in the snap and was secured by a bead and a double overhand knot (Figure C-2). The gangions were stored on hookboards where they could be baited or debaited as a group before and after being set (Figure C-3).

## Description of Gillnet Gear

Surface nets were 75 ft (22.9 m) long and sunken nets were 150 ft (45.7) long. Sunken nets were 10 ft (3.1 m) deep and surface nets were 20 ft (6.1 m). Leadline was 1.1 pound per fathom (0.27 kg per meter) for all gillnets, and cork spacing and size were variable as required to float a surface net or allow a bottom net to sink. Mesh sizes of 2.5, 3.5, and 4.0 in. (6.4, 8.9, 10.2 cm) stretch mesh were employed. Each 150 ft (45.7 m) net consisted of six 25 ft (7.6 m) panels, two of each mesh size installed in random order. Anchors (15 lb, 6.8 kg) and buoys were attached to each end of a net. Both bottom and floating nets were set horizontally and generally cross-current. Surface nets were used for both stationary and drift sets. The drift sets were set without anchors as close to the powerhouse as river turbulence allowed and drifted downstream for 15-30 minutes per set.

Nets were hand-set and hauled out of 30 gallon (114 liter) plastic garbage cans (Figure C-4). Normally, two people set and retrieved the nets, pulling the boat to the net at retrieval, without power. A hydraulic drum could be used in these operations, in which case one person could handle the nets.

## Description of Pot Gear, Lake Trap, and Beach Seine

Our pots were commercially built shrimp pots (Figure C-5). They consisted of a rectangular iron reinforcing bar framework (18"x18"x36", 46x46x91 cm) covered with 1 inch (2.54 cm) stretch mesh knotless netting. There were in-facing conical tunnels at each end which originally tapered to 1 inch (2.54 cm) diameter openings. The openings were modified to 3, 4 and 5 in. (7.6, 10.2, 12.7 cm) diameter to accommodate entrance of northern squawfish. Pots were baited with salmon smolts and fished singly with a buoyline on each. Usually, they were fished overnight.

The lake trap tested briefly for this study was used for previous predator/prey research on the Columbia river (Nigro et al. 1985). It had a 200 feet (61 m) long lead made of 1.5 inch (3.8 cm) bar measure nylon mesh and two 30 feet (9.1 m) long wings with 1.25 inch (3.2 cm) bar measure nylon mesh. The capture box had a 7 inch (17.8 cm) square opening and was made of 1 inch (2.5 cm) bar measure nylon mesh.

The beach seine was 96 feet (29.3 m) long and made out of 1/4 inch (0.64 cm) stretch mesh with a centrally located bunt. The depth of the seine was approximately 10 feet (3.05 m) at the bunt tapering to 4 feet (1.2 m) on either end. The net was deployed off the bow of a 22 foot Boston Whaler and retrieved by hand to shore.

## Purse Seine Field Sampling Procedures

We did not seine according to any regular temporal-spatial schedule. Much of the effort consisted of designing, outfitting, physically testing, and modifying the seine in various ways to physically *improve* its operation.

We first tested the gear in Lake Washington on 5 July, making four complete sets. Because of problems encountered, we modified the net-handling gear in several ways and removed half of the purse rings. On 7 July, we again tested in Lake Washington, making three sets and finding the gear mechanically satisfactory. These sets required approximately thirty minutes to set, retrieve and prepare for the next set.

Figure C-4. Gillnet gear.

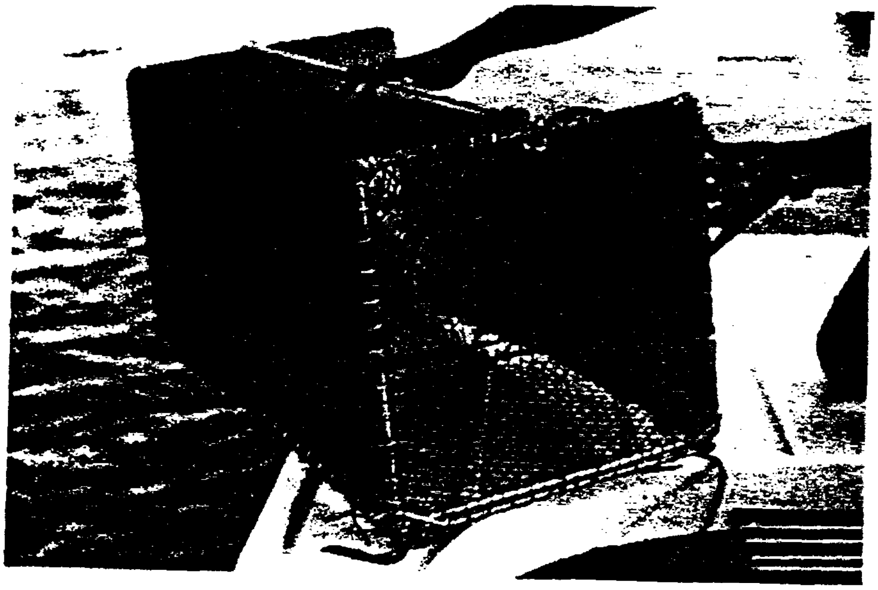


Figure C-5. Pot gear.

On 19 July, we tested the gear in mid-channel of the upper John Day reservoir in the vicinity of the Umatilla marina entrance. We surveyed the area with depth sounder first to find a suitably wide section 30 ft (9.1 m) deep or greater. We set, but snagged the bottom. The current (about 2.0 ft per second) caused the whole net to sink, and it was nearly lost. By cutting the purse line we were able to free it.

After repairs to the net, we next seined on 20 and 21 July near the Irrigon hatchery. Water depth was 40-60 ft (12.2-18.3 m) and current approximately 1.0 ft per second. We made five complete sets with no problems encountered. We fished this same area again on 23 July, making four sets at that time. We tried towing the net both upstream and downstream for 15-30 minutes before closing. The seining went smoothly and hauls required about 15 minutes each, or longer, depending on towing time.

We fished the spill basin below McNary Dam on several dates, beginning the week of 17-21 July. The water there was 30-40 ft (9.1-12.2 m) deep. There was little current in the center of the basin at this time. At the south end of the basin, near the Oregon ladder entrance, there was considerable turbulence, however. During one set, we were drawn into the turbulence, which caused the net to collapse and tangle. The net had to be taken ashore to straighten. We snagged the bottom with the seine several times in the spill basin even though the depth was 30 ft (9.1 m) or greater on the depth recorder. Apparently, the purse line hung down below 30 ft (9.1 m) in places.

We attempted one modification of the seine to allow it to be fished in shallower waters. We raised the leadline by placing vertical 20 ft (6.7 m) lines (#36 seine twine) between the cork and lead lines. These were placed at the breast lines (each end) of the net and above each of the rings. Thus, there were 27 vertical lines in total. So modified, the depth of the seine was limited to 22 ft (6.7 m) (including the 2 ft bridles for the rings). We made four sets with the modified seine in the McNary spill basin on 22 July. Catches of all species were substantially less than catches before modification. Furthermore, tangles were frequent and the seine did not appear to "hang" well. Purse rings tended to get caught between the vertical lines and the web. This modification did not seem to be an appropriate way to shallow the seine, and subsequently, the vertical lines were removed. To effectively shallow this seine, it would be necessary to rehang the net with shallower web.

In September, sets were made directly before or after longline sets and in identical locations in order to compare catching efficiency of these gear types. Most of this effort was based in the McNary forebay, although a few such paired sets were made in other transects of the upper John Day reservoir.

## Longline and Giiet Field Sampling Procedures

Five transects within the John Day reservoir were chosen for sampling during the summer months. These five areas include nearly all habitats identified within the reservoir by past studies (S. Vigg, C.C. Burley, ODF&W pers. comm.). The McNary transect includes the upstream faster current area of the reservoir; the Irrigon, Paterson, and Arlington areas represent slower current areas; and the John Day transect represents the very slow current "pool" portion of the reservoir.

Each transect was sampled during three separate weeks throughout the summer (15 May-12 August): Early, mid-, and late summer. A 12-week sampling schedule was devised in order to allow three weeks of sampling at each transect. Irrigon and Paterson transects were fished simultaneously because of their close proximity to one another. Three days of fishing were initially scheduled for each week, allowing two days each week for gear maintenance and laboratory work for the biological samples collected from the bottom gillnets (Vigg and Burley 1990). Generally speaking, this field schedule was met; however, heavy winds sometimes restricted the efficiency of our operations. During one week, the sampling was reduced to two days because of other activities, but the hours per day were increased accordingly.

Surface gillnets, bottom gillnets, and longlines were initially tested, but the surface gillnets were dropped after the first month of the sampling season because of their apparent inefficiency and in order to increase sampling effort with bottom gillnets.

The number of sets for each type of gear changed slightly throughout the summer; however, a typical daily routine would be:

- Set three bottom gillnets (or two bottom gillnets and one surface gillnet)
- Set two or three longlines (50-75 hooks)
- Pull all gillnets
- Set three more gillnets
- Pull all longlines
- Pull all gillnets

With this schedule we were able to fish the bottom and surface gillnets for approximately ♦•□ hours each and fish the longlines from three to four hours each. Sampling occurred at various hours throughout the day (Table C-2).

Table C-2. Frequency distribution for time of day of setting gillnets and longlines in the John Day reservoir, April-August 1989.

| | NUMBER OF SETS | |
|---|---|---|
| Hour of day | All Gillnets | Longline |
| 3 a.m. | 4 | 0 |
| 4 a.m. | 10 | 2 |
| 5 a.m. | 15 | 6 |
| 6 a.m. | 8 | 9 |
| 7 a.m. | 25 | 4 |
| 8 a.m. | 22 | 9 |
| 9 a.m. | 6 | 17 |
| 10 a.m. | 12 | 7 |
| 11 a.m. | 18 | 9 |
| 12 noon | 7 | 8 |
| 1 p.m. | 5 | 5 |
| 2 p.m. | 5 | 4 |
| 3 p.m. | 10 | 1 |
| 4 p.m. | 11 | 7 |
| 5 p.m. | 7 | 11 |
| 6 p.m. | 10 | 7 |
| 7 p.m. | 11 | 1 |
| 8 p.m. | 1 | 3 |
| 9 p.m. | 4 | 3 |
| 10 p.m. | 0 | 1 |
| Total | 191 | 114 |

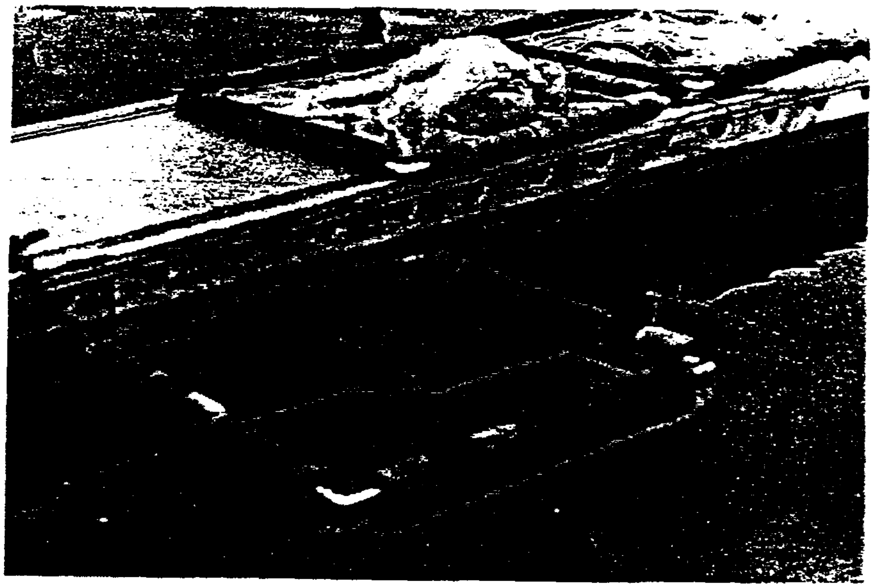
Data collected for each piece of gear were basically standard for most sampling: Location, start time and date, stop time and date, gear type, depth gear was fished, water temperature, and numbers of fish caught. We also tried collecting more general variables, but measurement difficulties were encountered. These variables were water turbidity, substrate type, wave height, and current speed. The Secchi disk reading was difficult to read in high waves (which was a common condition). Wave height was also difficult to measure and very subjective. A 0.025 cubic meter Van Veen grab sampler was initially used to determine bottom substrate; however, it would not retrieve anything but mud and silt. Small rocks would often stick in the jaws and hold the mouth open. It also did not work in heavy current or areas that had twigs and sticks on the bottom. Surface current was measured by the "floating chip" method, but this was suitable only on calm days when the boat speed was zero relative to the water speed.

During the fall we focused our efforts on developing the longline. Gillnets were occasionally fished in order to supplement a CPUE comparison between the gillnets and longlines. Longline sampling emphasized bait and hook comparisons, gear comparisons, soak time experiments, and commercial application tests. A new data sheet was designed which facilitated the recording of data on each hook. Data collected for each hook included depth fished, hook type, bait type, species and length of fish caught, hook location, catch condition, returning hook condition, and returning bait condition. Fishing occurred in three locations on the Columbia river; Irrigon, McNary tailrace (equivalent to the McNary transect of the summer sampling effort), and McNary forebay.

## Live Holding Observations

Recreationally important sportfish caught on the longline were held in live pens to test for hooking mortality from 2 June through 2 November. Three 4'x4'x8' deep (1.2x1.2x2.4 m) pens were used as well as one large pen, 8'x20'x8' deep (2.4x6.1x2.4 m) (Figure C-6). The pens were secured to the docks at the Umatilla marina. White sturgeon, *Acipenser transmontanus*, and channel catfish, *Ictalurus punctatus*, caught in the McNary transect were transported by boat in 30 gallon (114 liter) cans to the live pens. No other species of sportfish was caught often enough to be included in this study. Fish were held from three to seven days; however, all observed mortality occurred within the first day.

Due to irregular catches of white sturgeon and channel catfish, holding densities varied greatly. Fish collected throughout a week of sampling were held in a single pen and released at the beginning of the following week.



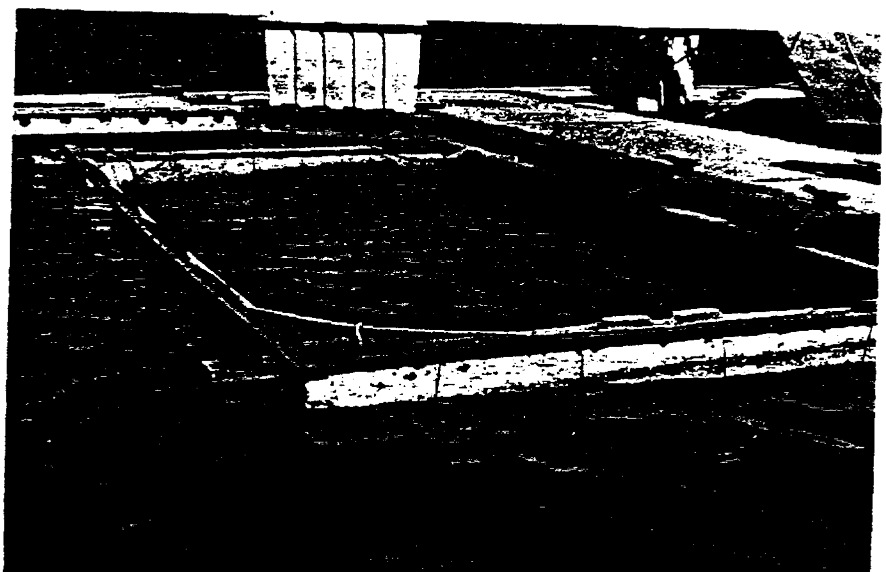


Figure c-6. Live holding pens.

## Baited Pots, Lake Trap, and Beach Seii Procedures

During the summer one baited pot was fished continuously for seven days in the Umatilla marina (12 ft, 3.7 m), and three pots were set overnight at the mouth of the Umatilla River on one occasion (7-15 ft, 2.1-4.6 m). In September, five pots were fished overnight for one night only and in October five pots were fished continuously for five days. Pot openings ranged from 3 to 5 inches in diameter.

A lake trap was set on 1 November and pulled on 3 November, 1989. The net was set perpendicular to shore at the McNary tailrace boat restricted zone boundary on the Oregon shore. It was checked every morning and evening. The lead was anchored on shore and the basket sat in roughly 25 feet of water.

Beach seining occurred from 3 October through 15 October. The primary emphasis of this gear was to capture juvenile American shad for use as bait on the longline. Seine hauls were made in the morning hours over sand or cobble substrate. Site selection was variable and sets were made until an adequate supply of American shad was captured for a day of longlining.

## RESULTS

### Purse Seining

Table C-3 summarizes the catches of all species by purse seining in the John Day reservoir and McNary forebay. A total of 92 northern squawfish was caught. American shad was the second most abundant species. With the exception of American shad, all non-squawfish released from the seine appeared healthy. American shad appeared weak at release and on two occasions dead ones were observed in the area after seining. These American shad may have been spawned-out, and thus weakened.

Each set took between 10 and 40 minutes to complete. The catch per unit of effort (CPUE) was calculated at 1.76 northern squawfish per set with a mean of about 20 minutes per set for all seine hauls, which resulted in a catch per hour of 3.917 northern squawfish.

The single set made off the Umatilla Marina on 19 July (which hung up) did yield 18 American shad, but no other species.

The nine sets made in the vicinity of the Irrigon hatchery yielded no fish. Mechanically, the gear seemed to work well. Because of the net depth and amount of current, we could not get too close to shore, where experience with other gear types suggested that fish would be found. We were restricted to the main channel of the river.

In the McNary spill basin we made a total of 17 successful sets (no hang-ups) in July, including four in which the net was "strung" to hang 22 ft (6.7 m) deep. One set was made in the spill basin in August and caught no squawfish.

In September, all sets made in the upper John Day reservoir were unsuccessful in capturing northern squawfish. We were successful in the McNary dam forebay in two locations. Three squawfish were captured in a no current, hold up area just above the lock entrance on the Washington side of the dam. These were all caught in separate seine hauls. One squawfish was caught in a low current area on the Oregon shore over a steep drop off approximately one half of a mile above the dam.

There was no detectable diurnal variation in catch rates, however, there is suggested temporal variation in the McNary spill basin. A more definitive sampling design is needed with a larger sampling effort before conclusions can be made.

Table C-3. catch per hour for purse seining in John Day reservoir 1989.

| Month / Transect | JULY Irrigon | | JULY McNary spill basin | | AUGUST McNary spill basin | |
|---|---|---|---|---|---|---|
| SPECIES | #FISH | CPUE | #FISH | CPUE | #FISH | CPUE |
| Northern squawfish | 0 | 0.000 | 88 | lo.588 | 0 | 0.000 |
| American shad | 0 | 0.000 | 51 | 6.706 | 1 | 2.000 |
| Catostomids | 0 | 0.000 | 29 | 4.471 | 2 | 4.000 |
| Carp | 0 | 0.000 | 13 | 1.529 | 2 | 4.000 |
| Steelhead | 0 | 0.000 | 4 | 0.588 | 0 | 0.000 |
| Chinook salmon | 0 | 0.000 | 4 | 0.471 | 1 | 2.000 |
| Sockeye salmon | 0 | 0.000 | 3 | 0.471 | 0 | 0.000 |
| Chiselmouth | 0 | 0.000 | 3 | 0.353 | 0 | 0.000 |
| Walleye | 0 | 0.000 | 1 | 0.118 | 0 | 0.000 |
| Total # sets | 9 | | 17 | | 1 | |
| Squawfish catch/set | 0 | | 5.18 | | 0 | |

| Month / Transect | SEPTEMBER Paterson | | McNary spill basin | | Irrigon | | McNary forebay | |
|---|---|---|---|---|---|---|---|---|
| SPECIES | # | CPUE | # | CPUE | 4 | CPUE | # | CPUE |
| Northern squawfish | 0 | 0.000 | 0 | 0.000 | 0 | 0.000 | 4 | 1.471 |
| American shad | 0 | 0.000 | 2 | 2.000 | 0 | 0.000 | 0 | 0.000 |
| Catostomids | 0 | 0.000 | 0 | 0.000 | 0 | 0.000 | 0 | 0.000 |
| Carp | 0 | 0.000 | 0 | 0.000 | 0 | 0.000 | 0 | 0.000 |
| Steelhead | 0 | 0.000 | 5 | 5.000 | 0 | 0.000 | 2 | 0.618 |
| Chinook salmon | 0 | 0.000 | 3 | 3.000 | 0 | 0.000 | 1 | 0.368 |
| Total # sets | 2 | | 4 | | 3 | | 16 | |
| Squawfish catch/set | 0 | | 0 | | 0 | | 0.25 | |

ALL AREAS AND MONTHS

| SPECIES | # | CPUE |
|---|---|---|
| Northern squawfish | 92 | 3.91402 |
| American shad | 54 | 2.38461 |
| Catostomids | 31 | 1.53846 |
| Carp | 15 | 0.57692 |
| Steelhead | 11 | 0.76696 |
| Chinook salmon | 9 | 0.53619 |
| Sockeye salmon | 3 | 0.15384 |
| Chiselmouth | 3 | 0.11538 |
| Walleye | 1 | 0.03846 |
| Total # sets | 52 | |
| Squawfish catch/set | 1.76 | |

## Longlining

Longlining was a very successful method in terms of maximum northern squawfish CPUE with minimum incidence of other species in the catch.

During the summer sampling period we made 115 sets. Number of hooks per set averaged 56 and ranged between 25-150. Average soak time averaged 5.5 hours and ranged from 15 minutes to 20 hours. Total hook-hours was 36,558. The northern squawfish catch totaled 525, which translated to about five fish per set or 0.0244 fish per hook-hour. In terms of hooks set per fish caught, the statistic commonly referred to in commercial longline fisheries, we averaged about 12 hooks/northern squawfish.

Northern squawfish comprised 72% of the fish caught on longlines (Table C-4a). Channel catfish and white sturgeon comprised 23%. The remaining 5% were suckers, American shad, carp, cottids, bullheads, and yellow perch. No bass, and surprisingly, no walleye were taken on longlines.

In terms of hooks set per northern squawfish caught, the highest success rate was in the McNary section. Here we caught 403 northern squawfish for 3,568 hooks set, an average of one northern squawfish per 8.9 hooks set. Catch rates as high as one fish per 4-5 hooks set were commonly encountered in the McNary section early in our test period. Success tended to decline towards the end of our sampling period. In the Arlington section, an average of 12.7 hooks was set per northern squawfish caught. In the other three sections, longlining was far less successful according to this measure, requiring 23-42 hooks per northern squawfish.

In terms of the alternative measure of success, squawfish per hook hour, the Irrigon area yielded the highest overall catch rate (Table C-5a), followed closely by the McNary section. However, such a comparison may be misleading in that we made a number of overnight sets in the McNary transect but not in the other sections and catch rates per hook hour tended to drop off significantly with length of time set. For all areas combined catch per hook hour was greatest in April, however, sampling effort was quite low during this month. May and July had the next highest catch per hook hour with 0.02 and 0.02. The overall mean for the summer sampling season for the longline was 0.02 northern squawfish per hook hour. This is equivalent to 1.2 squawfish per hour for a-50 hook longline.

Due to the results of the summer sampling season we focused our fall sampling effort in the McNary and Irrigon transects. Our goal was to determine affects of bait and hook type on catch rates and to record a by hook analysis of catch in order to determine depth distributions of northern squawfish. Also, tests to determine the application of the longline to a commercial fishery were attempted.

Table C-4a. Total catch by species from longlining in the John Day reservoir, April-August 1989.

| | TRANSECT | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PATERSON | | ARLINGTON | | JOHN DAY | | McNARY | | IRRIGON | | TOTAL | |
| | # | % | # | % | # | % | # | % | # | % | # | % |
| N.Squawfish | 26 | 60.5 | 57 | 75.0 | 26 | 66.7 | 403 | 75.3 | 13 | 39.4 | 525 | 72.5 |
| C. Catfish | 3 | 7.0 | 11 | 14.5 | 8 | 20.5 | 58 | 10.8 | 3 | 9.1 | 83 | 11.5 |
| W. Sturgeon | 4 | 9.3 | 0 | 0.0 | 2 | 5.1 | 60 | 11.2 | 15 | 45.5 | 81 | 11.2 |
| cottids | 9 | 20.9 | 2 | 2.6 | 1 | 2.6 | 0 | 0.0 | 2 | 6.1 | 14 | 1.9 |
| YellowPerch | 1 | 2.3 | 2 | 2.6 | 0 | 0.0 | 5 | 0.9 | 0 | 0.0 | 8 | 1.1 |
| Bullheads | 0 | 0.0 | 2 | 2.6 | 2 | 5.1 | 3 | 0.6 | 0 | 0.0 | 7 | 1.0 |
| Catostomids | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 4 | 0.7 | 0 | 0.0 | 4 | 0.6 |
| Carp | 0 | 0.0 | 2 | 2.6 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.3 |
| Am. Shad | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.4 | 0 | 0.0 | 2 | 0.3 |
| TOTAL | 43 | 0 | 76 | 60 | 39 | | 535 | | 33 | | 724 | |
| #sets | | 11 | | 14 | | 21 | | 59 | | 10 | | 115 |
| #hooks | | 600 | | 722 | | 1100 | | 3568 | | 455 | | 6445 |
| #hook*hours | | 1400 | | 3233 | | 8313 | | 22108 | | 1504 | | 36558 |

Table C-4b. Total catch by species from longlining by location for September-November 1989.

| | McNary tailrace | | McNary forebay | | TRANSECT Irrigon | | TOTAL | |
|---|---|---|---|---|---|---|---|---|
| | # | % | # | % | # | % | # | % |
| N.Squawfish | 103 | 58.5 | 17 | 53.1 | 9 | 81.8 | 129 | 58.9 |
| C. Catfish | 27 | 15.3 | 12 | 37.5 | 2 | 18.2 | 41 | 18.7 |
| W. Sturgeon | 18 | 10.2 | 0 | 0.0 | 0 | 0.0 | 18 | 8.2 |
| catostomids | 9 | 5.1 | 0 | 0.0 | 0 | 0.0 | 9 | 4.1 |
| YellowPerch | 6 | 3.4 | 1 | 3.1 | 0 | 0.0 | 7 | 3.2 |
| Bullheads | 6 | 3.4 | 0 | 0.0 | 0 | 0.0 | 6 | 2.7 |
| cottids | 4 | 2.3 | 0 | 0.0 | 0 | 0.0 | 4 | 1.8 |
| Carp | 3 | 1.7 | 0 | 0.0 | 0 | 0.0 | 3 | 1.4 |
| Sm.Mth.Bass | 0 | 0.0 | 2 | 6.3 | 0 | 0.0 | 2 | 0.9 |
| TOTAL | 176 | | 32 | | 11 | | 219 | |
| #sets | | 66 | | 11 | | 5 | | 82 |
| khooks | | 3175 | | 528 | | 240 | | 3943 |
| #hook*hours | | 19593 | | 1804 | | 1052 | | 22449 |

Table C-5a. Mean catch per hook hour by location, month, and species from longlining in the John Day reservoir for April-August 1989. Catch per hook hour = (# fish caught)/(# hooks fished * # hours fished) calculated for each individual set.

| | TRANSECT | | | | | |
|---|---|---|---|---|---|---|
| MONTH | PATERSON | ARLINGTON | JOHN DAY | McNARY | IRRIGON | ALL AREAS |
| **APRIL** | | | | | | |
| N.Squawfish | | | | 0.0766 | 0.2667 | 0.1038 |
| | | | | (779) | (8) | (786) |
| **MAY** | | | | | | |
| N.Squawfish | 0.0133 | | | 0.0247 | 0 0073 | 0.0228 |
| C. Catfish | 0.0133 | | | 0.0048 | 0 0000 | 0.0051 |
| W. Sturgeon | 0.0000 | | | 0.0026 | 0 0073 | 0.0027 |
| Catostomids | 0.0000 | | | 0.0014 | 0.0000 | 0.0012 |
| Bullheads | 0.0000 | | | 0.0009 | 0.0000 | 0.0008 |
| YellowPerch | 0.0000 | | | 0.0005 | 0.0000 | 0.0005 |
| | (150) | | | (5712) | (138) | (6000) |
| **JUNE** | | | | | | |
| N.Squawfish | 0.0283 | 0.0080 | 0.0016 | 0.0175 | 0.0049 | 0.0122 |
| W. Sturgeon | 0.0052 | 0.0000 | 0.0008 | 0.0009 | 0.0153 | 0.0027 |
| Cottids | 0.0111 | 0.0020 | 0.0001 | 0.0000 | 0.0022 | 0.0021 |
| C. Catfish | 0.0000 | 0.0000 | 0.0004 | 0.0041 | 0.0029 | 0.0019 |
| YellowPerch | 0.0013 | 0.0000 | 0.0000 | 0.0007 | 0.0000 | 0.0005 |
| Bullheads | 0.0000 | 0.0020 | 0.0002 | 0.0000 | 0.0000 | 0.0003 |
| | (637) | (1424) | (5763) | (8630) | (617) | (17071) |
| **JULY** | | | | | | |
| N.Squawfish | 0.0139 | 0.0331 | 0.0054 | 0.0305 | 0.0098 | 0.0251 |
| W. Sturgeon | 0.0000 | 0.0000 | 0.0000 | 0.0080 | 0.0000 | 0.0042 |
| C. Catfish | 0.0018 | 0.0065 | 0.0034 | 0.0012 | 0.0026 | 0.0026 |
| YellowPerch | 0.0000 | 0.0018 | 0.0000 | 0.0001 | 0.0000 | 0.0004 |
| Bullheads | 0.0000 | 0.0013 | 0.0000 | 0.0000 | 0.0000 | 0.0002 |
| Carp | 0.0000 | 0.0012 | 0.0000 | 0.0000 | 0.0000 | 0.0002 |
| Am. Shad | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | 0.0001 |
| Cottids | 0.0000 | 0.0005 | 0.0000 | 0.0000 | 0.0000 | 0.0001 |
| Catostomids | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | 0.0001 |
| | (613) | (1646) | (1750) | (6428) | (742) | (11179) |
| **AUGUST** | | | | | | |
| N.Squawfish | | 0.0061 | 0.0135 | 0.0341 | | 0.0196 |
| C. Catfish | | 0.0000 | 0.0013 | 0.0062 | | 0.0028 |
| | | (163) | (800) | (560) | | (1523) |
| **APRIL-AUGUST** | | | | | | |
| N.Squawfish | 0.0217 | 0.0222 | 0.0052 | 0.0308 | 0.0333 | 0.0244 |
| W. Sturgeon | 0.0028 | 0.0000 | 0.0004 | 0.0038 | 0.0069 | 0.0029 |
| C. Catfish | 0.0019 | 0.0037 | 0.0012 | 0.0029 | 0.0022 | 0.0025 |
| Cottids | 0.0061 | 0.0010 | 0.0000 | 0.0000 | 0.0009 | 0. 0008 |
| YellowPerch | 0.0007 | 0.0010 | 0.000.0 | 0.0003 | 0.0000 | 0.0004 |
| Bullheads | 0.0000 | 0.0014 | 0.0001 | 0.0002 | 0.0000 | 0.0003 |
| Catostomids | 0.0000 | 0.0000 | 0.0000 | 0.0004 | 0.0000 | 0.0002 |
| Carp | 0.0000 | 0.0007 | 0.0000 | 0.0000 | 0.0000 | 0.0001 |
| Am. Shad | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 |
| | (1401) | (3233) | (8313) | (22109) | (1505) | (36561) |

(total # hook*hours)

CPUE for the longlines decreased to 0.01 northern squawfish per hook hour for the fall sampling season (Table C-5b). A total of 82 longlines was set in three areas; McNary tailrace, McNary forebay, and Irrigon. This resulted in a total of 22,449 hook hours. 129 northern squawfish were caught, constituting 58.9% of the total catch of all species (Table C-4b). Tables 5a and 5b show a decrease in CPUE for the major species in the Irrigon and McNary tailrace transects from the summer sampling period to the fall sampling period.

### Bait Comparisons

Catch rates for various baits are shown in Table C-6. These baits were all fished on 3/0 steelhead hooks in the McNary transect (just below McNary dam). In the fall, American shad young of the year proved to be the most effective bait. These fish are abundant throughout the reservoir at this time of the year and it is not surprising that the squawfish may tend to target this particular food base. Salmon smolts were the next best bait for fall sampling; however, the catch efficiency of smolts decreased substantially from one squawfish caught per 7.5 hooks set during the summer months to one squawfish per 21 hooks set in the fall.

Salmon eggs were tried in the spring, however, they did not last very long on the hook and after a 2-hour set most of the baits were gone all together. It is interesting to note that nightcrawlers had an extremely high incidence of non-squawfish catch. In relatively few trials crayfish had fair catch rates on squawfish and no incidental catch; however, they are very difficult to place on a hook and even more difficult to remove.

### Hook Comparisons

Catch rate is only one of many important factors in choosing the best hook type for this longline. Other important considerations include: ease of handling and baiting, ease of removal from fish, and ease of maintenance of the hook (i.e. keeping the hook sharp and unbent).

The 3/0 circle hook was not a good hook for this longline. When tested in the spring, the catch rates were similar to those of the 3/0 steelhead hooks but they were difficult to remove from channel catfish and white sturgeon without damaging the fish. They were also more difficult to bait and debait. The double 3/0 steelhead hook setups did not show a very high catch rate (Table C-6). They were more difficult to handle and time consuming to bait and debait. The Kirby 3/0 tinned "J" hook had the best catch rate and a very low incidental catch rate. However, they do not stay sharp for very long and thus have to be sharpened quite often.

Table C-5b. Mean catch per hook hour by location, month, and species from longlining for September-November 1989.
Catch per hook hour =
(# fish caught)/(# hooks fished * # hours fished)
calculated for each individual set.

| | TRANSECT | | | |
|---|---|---|---|---|
| MONTH | Irrigon | McNary tailrace | McNary forebay | ALL AREAS |
| September | | | | |
| N.Squawfish | 0.0099 | 0.0042 | 0.0107 | 0.0067 |
| c. Catfish | 0.0019 | 0.0010 | 0.0088 | 0.0032 |
| YellowPerch | 0.0000 | 0.0005 | 0.0007 | 0.0005 |
| Sm.Mth.Bass | 0.0000 | 0.0000 | 0.0016 | 0.0004 |
| W. Sturgeon | 0.0000 | 0.0005 | 0.0000 | 0.0003 |
| Bullheads | 0.0000 | 0.0003 | 0.0000 | 0.0002 |
| Carp | 0.0000 | 0.0001 | 0.0000 | 0.0001 |
| | (1052) | (7641) | (1804) | (10497) |
| October | | | | |
| N.Squawfish | | 0.0132 | | 0.0132 |
| C. Catfish | | 0.0031 | | 0.0031 |
| W. Sturgeon | | 0.0014 | | 0.0014 |
| Bullheads | | 0.0006 | | 0.0006 |
| cottids | | 0.0005 | | 0.0005 |
| YellowPerch | | 0.0002 | | 0.0002 |
| Carp | | 0.0001 | | 0.0001 |
| | | (7452) | | (7452) |
| November | | | | |
| Catostomids | | 0.0027 | | 0.0027 |
| N.Squawfish | | 0.0020 | | 0.0.020 |
| W. Sturgeon | | 0.0011 | | 0.0011 |
| YellowPerch | | 0.0005 | | 0.0005 |
| C. Catfish | | 0.0004 | | 0.0004 |
| Cottids | | 0.0001 | | 0.0001 |
| | | (4500) | | (4500) |
| September-November | | | | |
| N.Squawfish | 0.0099 | 0.0074 | 0.0107 | 0.0080 |
| C. Catfish | 0.0019 | 0.0017 | 0.0088 | 0.0027 |
| W. Sturgeon | 0.0000 | 0.0010 | 0.0000 | 0.0008 |
| Catostomids | 0.0000 | 0.0006 | 0.0000 | 0.0005 |
| YellowPerch | 0.0000 | 0.0004 | 0.0007 | 0.0004 |
| Bullheads | 0.0000 | 0.0003 | 0.0000 | 0.0003 |
| Sm.Mth.Bass | 0.0000 | 0.0000 | 0.0016 | 0.0002 |
| Cottids | 0.0000 | 0.0002 | 0.0000 | 0.0002 |
| Carp | 0.0000 | 0.0001 | 0.0000 | 0.0001 |
| | (1052) | (19593) | (1804) | (22449) |

(total # hook*hours)

Table C-6. Catch summaries for various baits and hooks used for longlining in the McNary transect of the John Day reservoir, 1989.

Bait comparisons
(All single 3/0 Steelhead hooks)

| | Number of hooks set | Squawfish catch | Incidental catch | % SQF | Hooks set/ SQF caught |
|---|---|---|---|---|---|
| JUNE-AUGUST | | | | | |
| Bait | | | | | |
| Salmon smolts | 795 | 106 | 29 | 78.52 | 7.5 |
| SEPTEMBER-NOVEMBER | | | | | |
| Bait | | | | | |
| American shad | 312 | 18 | 10 | 64.29 | 17.33 |
| Salmon smolts | 1284 | 61 | 33 | 64.89 | 21.05 |
| Crayfish | 96 | 3 | 0 | 100.00 | 32.00 |
| Small cottids | 72 | 2 | 1 | 66.67 | 36.00 |
| Nightcrawlers | 480 | 6 | 15 | 28.57 | 80.00 |
| Herring | 192 | 0 | 0 | 0.00 | 0.00 |
| Sucker pieces | 36 | 0 | 0 | 0.00 | 0.00 |
| Trout perch | 72 | 0 | 3 | 0.00 | 0.00 |

Hook comparisons
(All salmon smolt bait)

| | Number of hooks set | Squawfish catch | Incidental catch | % SQF | Hooks set/ SQF caught |
|---|---|---|---|---|---|
| JUNE-AUGUST | | | | | |
| Hook type | | | | | |
| 3/0 Kirby "J" | 50 | 11 | 0 | 100.00 | 4.55 |
| 3/0 Kahle "English Bait" | 412 | 78 | 14 | 84.78 | 5.28 |
| 3/0 Steelhead | 1157 | 147 | 44 | 76.96 | 7.87 |
| SEPTEMBER-NOVEMBER | | | | | |
| Hooks | | | | | |
| 3/0 Kirby "J" | 108 | 6 | 1 | 85.71 | 18.00 |
| 3/0 Steelhead | 1272 | 62 | 33 | 65.26 | 20.52 |
| Double 3/0 Steelhead | 108 | 1 | 2 | 33.33 | 108.00 |

The two best hooks are the 3/0 steelhead and the 3/0 Kahle horizontal (English bait) hook. Both are easy to bait and debait, easy to sharpen, and they stay sharp after many uses. The Kahle horizontal hook is potentially the best hook. It had better results in catch comparisons than the steelhead hook and is also very easy to bait and debait. In tests against the steelhead hook the Kahle design caught 1.5 times as many squawfish. Longlines were set with 50% Kahle hooks and 50% steelhead hooks and all hooks were baited with salmon smolts. A total of 412 hooks of each type was fished; the Kahle caught 78 squawfish and the steelhead hook caught 51.

### Depth Distribution of Northern Squawfish

During the fall sampling season, longlines were fished from surface to bottom in order to estimate the depth distribution of northern squawfish. Twelve hooks were evenly distributed over each section of longline, between an anchor and a float, so that the relative fishing depth of each individual hook could be estimated. Hooks were numbered from surface to bottom (Figure C-7) and by dividing this hook location number by 13 and multiplying this number by the actual water depth, an estimate of the actual depth that each hook was fishing could then be calculated. Thus depth of capture for each squawfish was estimated. Considering the length of the gangion and error involved due to the longline not hanging straight, these measurements nonetheless should be relatively accurate to the nearest three feet.

Fish were caught effectively at all depths in the water column. Table C-7 shows distribution of squawfish by depth of capture and depth of set. The number of sets made at each depth was highly variable, however, it becomes readily apparent that, at least during the fall, squawfish tend to be distributed throughout the water column, independent of water depth. However, in sets in 30 feet of water and deeper squawfish tended to be less oriented with the surface than in sets in shallower water.

Even though depth of capture for northern squawfish was not recorded during the summer sampling period, our observations strongly suggest that the squawfish were scattered throughout the water column at that time of year as well.

### Commercial Application Tests

Tests were done in order to determine the amount of longline gear that could be set during an 8 hour day and the amount of gear maintenance needed to maintain this level of fishing for a period of three days. We determined that two fishermen in one boat could effectively fish 500 hooks a day (ten 50 hook longlines) with an anticipated hook loss rate of

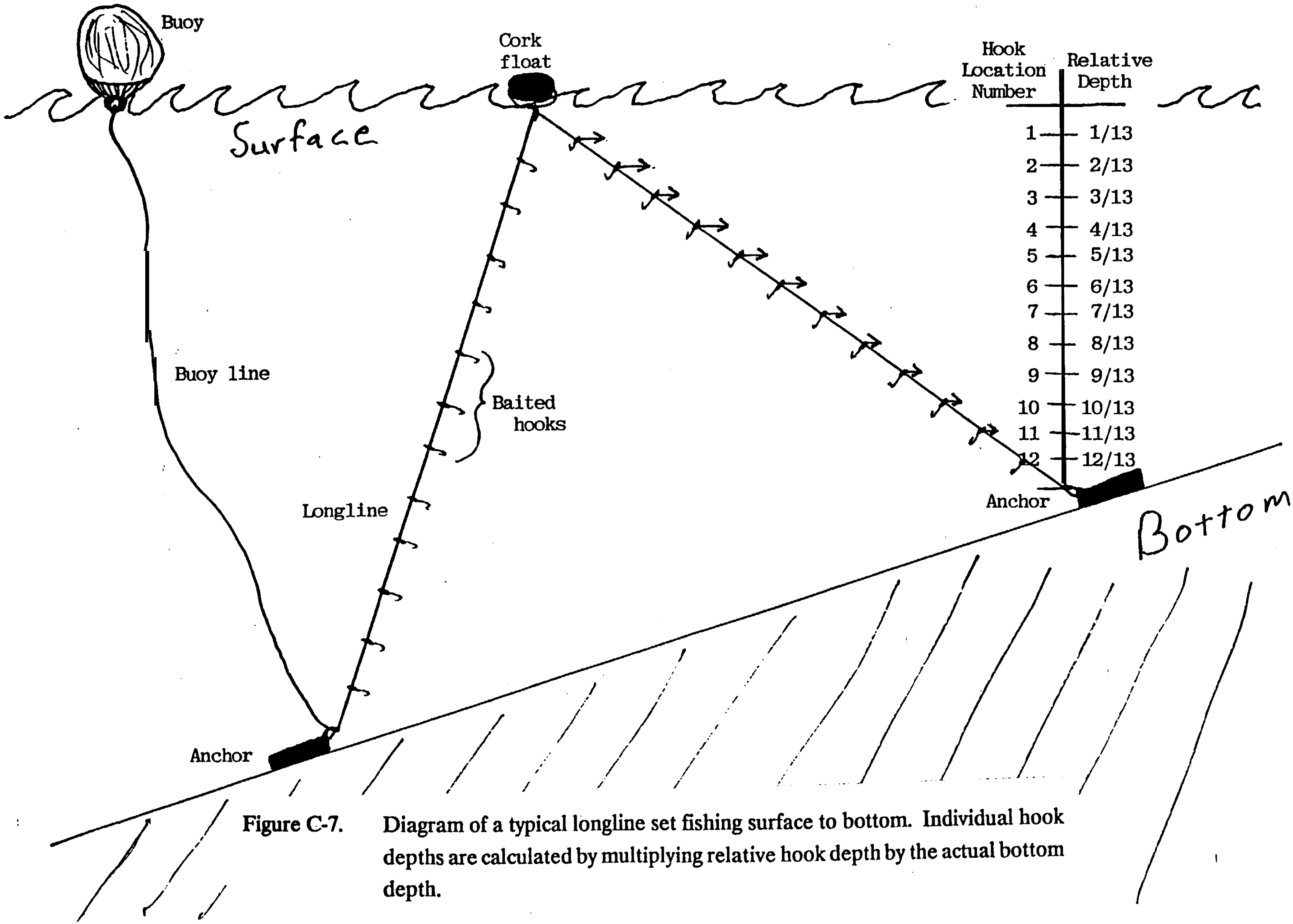



**Figure C-7.** Diagram of a typical longline set fishing surface to bottom. Individual hook depths are calculated by multiplying relative hook depth by the actual bottom depth.

Table C-7. Vertical location of capture of northern squawfish on longlines stratified by depth of water in which individual sets were made (September - November, 1989).

| Approximate Depth of Water in Which Gear was Set -> | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 | 70 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Approximate Depth of Capture on the Lines ft.** | | | | | | | | | | | | | |
| 1 | 1 | 4 | | | | | | | | | | | |
| 2 | 3 | 8 | 1 | 1 | 1 | | | | | | | | |
| 3 | 2 | 4 | 2 | 3 | | | | | | | | | |
| 4 | | 4 | | | 1 | | | | | | | | |
| 5 | | 6 | | 2 | | | | | | | | | |
| 6 | | 4 | 2 | 1 | 1 | | | | | | | | |
| 7 | | 4 | | | | | | | | | | | |
| 8 | | 9 | 1 | 1 | 1 | | | | | | | | |
| 9 | | 1 | 2 | 4 | | | | 1 | | | | | |
| 10 | | | 1 | | | | | | | | | | |
| 11 | | | | 1 | | | | | | | | | |
| 12 | | | 1 | 5 | 1 | | | 1 | | | | | |
| 13 | | | | | 1 | | | | | | | | |
| 14 | | | | 4 | | 1 | | | | | | | |
| 15 | | | | 1 | 1 | | | 1 | | | | | |
| 16 | | | | | | | | | | | | | |
| 17 | | | | 4 | 3 | | | | | | | | |
| 18 | | | | 2 | | 1 | | 1 | | | | | 1 |
| 19 | | | | | | | | | | | | | |
| 20 | | | | | | | | | | | | | |
| 21 | | | | | 1 | 1 | | | | | | | |
| 22 | | | | | | | | | | | | | |
| 23 | | | | | 1 | 1 | | | | | 1 | | |
| 24 | | | | | | | | | | | | | |
| 25 | | | | | | 3 | | 1 | | | | | |
| 26 | | | | | | | | | | | | | |
| 27 | | | | | | | 3 | | | | | | |
| 28 | | | | | | 1 | | | | | | | |
| 29 | | | | | | | | | | | | | |
| 30 | | | | | | | 1 | | | | | | |
| 31 | | | | | | | | 1 | 1 | | | | |
| 32 | | | | | | | | | | | | | |
| 33 | | | | | | | | | | | | | |
| 34 | | | | | | | | 1 | | | | | |
| 35 | | | | | | | | | | | | | |
| 36 | | | | | | | | | | | | | |
| 37 | | | | | | | | 1 | | | 1 | | |
| 38 | | | | | | | | | 1 | | | | |
| 39 | | | | | | | | | | | | | |
| 40 | | | | | | | | | | | | | |
| 41 | | | | | | | | | | | | | |
| 42 | | | | | | | | | 1 | | | | |
| 43 | | | | | | | | | | | | | 1 |
| 44 | | | | | | | | | | | | | |
| 45 | | | | | | | | | | | | | |
| 50 | | | | | | | | | | | | | |
| 55 | | | | | | | | | | | 1 | | |
| **Total Squawfish** | 6 | 44 | 10 | 29 | 12 | 8 | 4 | 8 | 3 | 0 | 3 | 0 | 2 |

Number of Squawfish Caught

approximately 4.5% per day. This means that it would take approximately three hours to set ten longlines; including fueling boat, travel time between each location, and baiting hooks as a group before each 5 longlines. It also takes approximately 4 hours to pull ten longlines, depending on catch sizes. This leaves approximately one hour to replace broken hooks and gangions, sharpen hooks, dispose of fish, and maintain boat and other gear.

**Gillnetting**

Bottom gillnetting was surprisingly ineffectual for northern squawfish and the catch of incidental species was relatively high. Northern squawfish comprised only 15% of the fish caught in the bottom gillnets. Bridgelip and largemouth suckers comprised 59% of the catch in numbers. Important recreational fish (American shad, white sturgeon, channel catfish, walleye, small mouth bass, salmon, steelhead, white crappie, and yellow perch) comprised 25% of the catch in numbers (Table C-8).

A total of 175 bottom gillnet sets was made throughout the John Day reservoir during both the summer and fall sampling periods; data from 165 of these were for biological monitoring purposes (Vigg and Burley 1990). Soak time averaged 2.37 hours. A total of 136 northern squawfish was caught by bottom gillnets or about 0.3 per gillnet hour overall (Table C-9). Of the 136 northern squawfish, 118 were caught during biological monitoring (Vigg and Burley 1990). The McNary and John Day transects yielded higher northern squawfish catches per gillnet hour (0.49 and 0.39) than the middle three sections. The high variability in catch rates for northern squawfish by month in Table C-9 is probably an artifact of irregular sampling and small sample sizes and not indicative of true time dependent catch rates.

Drift gillnetting with 75-ft lengths in the McNary tail race yielded no fish of any kind in two tests.

Surface-floating set nets yielded a few northern squawfish (Table C-10) but this gear was deemed relatively inefficient after early testing, and therefore was discontinued near the beginning of the summer sampling season to allow for increased bottom gillnetting effort and biological data collection. The ratio of incidental catch to squawfish catch was lower in the surface nets than in the bottom gillnets.

Table C-8. Total catch by species from bottom gillnetting in the John Day reservoir, April-October 1989.

| | PATERSON # | PATERSON % | ARLINGTON # | ARLINGTON % | TRANSECT JOHN DAY # | TRANSECT JOHN DAY % | McNARY # | McNARY % | IRRIGON # | IRRIGON % | TOTAL # | TOTAL % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Catostomids | 9 | 37.5 | 165 | 79.3 | 215 | 63.4 | 123 | 42.1 | 30 | 50.8 | 542 | 58.8 |
| N.Squawfish | 3 | 12.5 | 23 | 11.1 | 39 | 11.5 | 65 | 22.3 | 6 | 10.2 | 136 | 14.8 |
| Am. Shad | 1 | 4.2 | 7 | 3.4 | 37 | 10.9 | 24 | 8.2 | 7 | 11.9 | 76 | 8.2 |
| W. Sturgeon | 2 | 8.3 | 0 | 0.0 | 0 | 0.0 | 46 | 15.8 | 8 | 13.6 | 56 | 6.1 |
| C. Catfish | 1 | 4.2 | 4 | 1.9 | 32 | 9.4 | 7 | 2.4 | 1 | 1.7 | 45 | 4.9 |
| Chiselmouth | 2 | 8.3 | 3 | 1.4 | 7 | 2.1 | 1 | 0.3 | 1 | 1.7 | 14 | 1.5 |
| Walleye | 0 | 0.0 | 1 | 0.5 | 0 | 0.0 | 13 | 4.5 | 0 | 0.0 | 14 | 1.5 |
| Sm.Mth.Bass | 5 | 20.8 | 1 | 0.5 | 3 | 0.9 | 2 | 0.7 | 0 | 0.0 | 11 | 1.2 |
| Steelhead | 1 | 4.2 | 0 | 0.0 | 4 | 1.2 | 3 | 1.0 | 2 | 3.4 | 10 | 1.1 |
| All Carp | 0 | 0.0 | 1 | 0.5 | 0 | 0.0 | 1 | 0.3 | 2 | 3.4 | 4 | 0.4 |
| AllBullhead | 0 | 0.0 | 1 | 0.5 | 2 | 0.6 | 0 | 0.0 | 0 | 0.0 | 3 | 0.3 |
| YellowPerch | 0 | 0.0 | 1 | 0.5 | 0 | 0.0 | 2 | 0.7 | 0 | 0.0 | 3 | 0.3 |
| All Crappie | 0 | 0.0 | 1 | 0.5 | 0 | 0.0 | 1 | 0.3 | 1 | 1.7 | 3 | 0.3 |
| Coho Salmon | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 1 | 1.7 | 2 | 0.2 |
| Sockeye S. | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.7 | 0 | 0.0 | 2 | 0.2 |
| Chinook S. | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 0 | 0.0 | 1 | 0.1 |
| TOTAL | 24 | | 208 | | 339 | | 292 | | 59 | | 922 | |
| *sets | | 13 | | 34 | | 48 | | 49 | | 29 | | 173 |
| #gillnet hours | | 25.7 | | 82.5 | | 98.4 | | 143.9 | | 59.1 | | 409.5 |

Table C-9. Mean catch per gillnet hour by species for bottom gillnetting in the John Day reservoir, April-October 1989.

| MONTH | | PATERSON | ARLINGTON | JOHN DAY | McNARY | IRRIGON | ALL AREAS |
|---|---|---|---|---|---|---|---|
| | | | | TRANSECT | | | |
| APRIL | | | | | | | |
| | N.Squawfish | | | | 3.0000 | | 3.0000 |
| MAY | | | | | | | |
| | Catostomids | 0.2500 | | | 2.2581 | 1.3214 | 1.5219 |
| | N.Squawfish | 0.2500 | | | 0.3250 | 0.2857 | 0.2964 |
| | Chiselmouth | 0.0000 | | | 0.1250 | 0.2857 | 0.1339 |
| | Coho Salmon | 0.0000 | | | 0.1250 | 0.2857 | 0.1339 |
| | Carp | 0.0000 | | | 0.1366 | 0.0000 | 0.0683 |
| JUNE | | | | | | | |
| | Catostomids | 0.2830 | 1.2808 | 1.6346 | 1.0167 | 0.0000 | 0.9845 |
| | Am. Shad | 0.0714 | 0.0500 | 0.7137 | 0.2500 | 0.0714 | 0.2812 |
| | N.Squawfish | 0.0000 | 0.1578 | 0.2821 | 0.4037 | 0.0000 | 0.2059 |
| | C. Catfish | 0.0714 | 0.0500 | 0.2433 | 0.0833 | 0.0000 | 0.1054 |
| | W. Sturgeon | 0.1374 | 0.0000 | 0.0000 | 0.2648 | 0.0000 | 0.0845 |
| | Chiselmouth | 0.1429 | 0.0628 | 0.0000 | 0.0000 | 0.0000 | 0.0332 |
| | Sm.Mth.Bass | 0.0714 | 0.0000 | 0.0805 | 0.0000 | 0.0000 | 0.0316 |
| | Walleye | 0.0000 | 0.0000 | 0.0000 | 0.0787 | 0.0000 | 0.0193 |
| | YellowPerch | 0.0000 | 0.0500 | 0.0000 | 0.0000 | 0.0000 | 0.0102 |
| | Sockeye S. | 0.0000 | 0.0000 | 0.0000 | 0.0417 | 0.0000 | 0.0102 |
| | Steelhead | 0.0687 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0098 |
| JULY | | | | | | | |
| | Catostomids | 0.4722 | 1.8681 | 2.4651 | 1.0475 | 0.6250 | 1.4156 |
| | N.Squawfish | 0.2222 | 0.2432 | 0.5143 | 0.3341 | 0.1250 | 0.2878 |
| | Am. Shad | 0.0000 | 0.1500 | 0.4778 | 0.2783 | 0.1500 | 0.2387 |
| | W. Sturgeon | 0.0000 | 0.0000 | 0.0000 | 0.5895 | 0.2000 | 0.1821 |
| | C. Catfish | 0.0000 | 0.0721 | 0.4406 | 0.0887 | 0.0250 | 0.1363 |
| | Sm.Mth.Bass | 0.4722 | 0.0240 | 0.0313 | 0.0000 | 0.0000 | 0.0373 |
| | Chiselmouth | 0.0000 | 0.0000 | 0.1288 | 0.0000 | 0.0000 | 0.0268 |
| | Walleye | 0.0000 | 0.0230 | 0.0000 | 0.0916 | 0.0000 | 0.0262 |
| | Carp | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0500 | 0.0130 |
| | Steelhead | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0500 | 0.0130 |
| | Crappie | 0.0000 | 0.0250 | 0.0000 | 0.0000 | 0.0250 | 0.0130 |
| | YellowPerch | 0.0000 | 0.0000 | 0.0000 | 0.0294 | 0.0000 | 0.0065 |
| | Bullheads | 0.0000 | 0.0000 | 0.0278 | 0.0000 | 0.0000 | 0.0058 |
| | Chinook S. | 0.0000 | 0.0000 | 0.0000 | 0.0096 | 0.0000 | 0.0021 |
| | Sockeye S. | 0.0000 | 0.0000 | 0.0000 | 0.0047 | 0.0000 | 0.0010 |
| AUGUST | | | | | | | |
| | Catostomids | | 3.9808 | 2.3047 | 0.8333 | | 2.1004 |
| | N.Squawfish | | 0.2452 | 0.3684 | 0.3827 | | 0.3570 |
| | C. Catfish | | 0.0000 | 0.2895 | 0.0000 | | 0.1719 |
| | Steelhead | | 0.0000 | 0.1053 | 0.1111 | | 0.0938 |
| | W. Sturgeon | | 0.0000 | 0.0000 | 0.2222 | | 0.0625 |
| | Am. Shad | | 0.0000 | 0.0263 | 0.1605 | | 0.0608 |
| | Chiselmouth | | 0.0000 | 0.0526 | 0.0000 | | 0.0313 |
| | Bullheads | | 0.1250 | 0.0263 | 0.0000 | | 0.0313 |
| | Sm.Mth.Bass | | 0.0000 | 0.0000 | 0.0988 | | 0.0278 |
| | Walleye | | 0.0000 | 0.0000 | 0.0556 | | 0.0156 |
| | YellowPerch | | 0.0000 | 0.0000 | 0.0556 | | 0.0156 |
| | Carp | | 0.1250 | 0.0000 | 0.0000 | | 0.0156 |

Table C-9 Icontinued).

| MONTH | PATERSON | ARLINGTON | JOHN DAY | McNARY | IRRIGON | ALL AREAS |
|---|---|---|---|---|---|---|
| | | | TRANSECT | | | |
| SEPTEMBER | | | | | | |
| Catostomids | | | | 0.6667 | | 0.6667 |
| Crappie | | | | 0.2222 | | 0.2222 |
| W. Sturgeon | | | | 0.2222 | | 0.2222 |
| N.Squawfish | | | | 0 | | 0 |
| OCTOBER | | | | | | |
| N.Squawfish | | | | 1.6528 | | 1.6528 |
| Catostomids | | | | 1.0556 | | 1.0556 |
| W. Sturgeon | | | | 0.1250 | | 0.1250 |
| Steelhead | | | | 0.1250 | | 0.1250 |
| Chinook S. | | | | 0.1250 | | 0.1250 |
| APRIL-OCTOBER | | | | | | |
| Catostomids | 0.3361 | 1.9439 | 2.1767 | 1.0215 | 0.5222 | 1.3472 |
| N.Squawfish | 0.1068 | 0.2183 | 0.3937 | 0.4878 | 0.1059 | 0. 319'1 |
| Am. shad | 0.0385 | 0.1029 | 0.3630 | 0.1799 | 0.1207 | 0.1919 |
| C. Catfish | 0.0385 | 0.0571 | 0.3273 | 0.0492 | 0.0172 | 0.1267 |
| W. Sturgeon | 0.0740 | 0.0000 | 0.0000 | 0.3165 | 0.1379 | 0.1173 |
| Chiselmouth | 0.0769 | 0.0185 | 0.0638 | 0.0098 | 0.0197 | 0.0345 |
| Sm.Mth.Bass | 0.1838 | 0.0141 | 0.0322 | 0.0174 | 0.0000 | 0.0295 |
| Steelhead | 0.0370 | 0.0000 | 0.0417 | 0.0294 | 0.0345 | 0.0277 |
| Walleye | 0.0000 | 0.0136 | 0.0000 | 0.0588 | 0.0000 | 0.0192 |
| Carp | 0.0000 | 0.0147 | 0.0000 | 0.0107 | 0.0345 | 0.0114 |
| YellowPerch | O.GOOO | 0.0147 | 0.0000 | 0.0196 | 0.0000 | 0.0083 |
| Bullheads | 0.0000 | 0.0147 | 0.0197 | 0.0000 | 0.0000 | 0.0080 |
| Crappie | 0.0000 | 0.0147 | 0.0000 | 0.0087 | 0.0172 | 0.0080 |
| Coho Salmon | 0.0000 | 0.0000 | 0.0000 | 0.0098 | 0.0197 | 0.0060 |
| Chinook S. | 0.0000 | 0.0000 | 0.0000 | 0.0130 | 0.0000 | 0.0037 |
| Sockeye S. | 0.0000 | 0.0000 | 0.0000 | 0.0114 | 0.0000 | 0.0032 |

| MONTH | McNARY FOREBAY |
|---|---|
| SEPTEMBER | |
| N.Squawfish | 0.8889 |
| C. Catfish | 0.8205 |
| Chiselmouth | 0.2222 |
| Am. Shad | 0.2222 |
| Catostomids | 0.1538 |

Table C-10. Total catch and effort by species and location for surface gillnets in the John Day resevoir, May-September 1989. (CPUE = northern squawfish per gillnet hour)

| Species | McNary tailrace | Irrigon | Paterson | Arlington | John Day | McNary forebay |
|---|---|---|---|---|---|---|
| Catostomids | 2 | 0 | 1 | 6 | 0 | 0 |
| Northern squawfish | 0 | 0 | 0 | 8 | 1 | 0 |
| American shad | 0 | 0 | 0 | 7 | 0 | 0 |
| Chiselmouth | 2 | 0 | 0 | 0 | 0 | 0 |
| Channel catfish | 0 | 0 | 0 | 1 | 0 | 0 |
| TOTAL | | | | | | |
| Gillnet hours | 13.58 | 0.33 | 6 | 26.84 | 6.08 | 7.67 |
| Gillnets Set | 6 | 5 | 3 | 7 | 3 | 3 |
| Northern Squawfish CPUE | 0 | 0 | 0 | 0.3 | 0.16 | 0 |

## Baited Pots, Lake Trap, and Beach Seining

In a total of 37 pot nights, two small northern squawfish, three cottids, one small Steelhead, and thirty-one crayfish were captured. Both northern squawfish were under 250 mm in length. The crayfish were used as bait for the longline and the other fish were released into the reservoir.

The lake trap was set for a total of 48 hours. Eight northern squawfish were captured with a mean of 365 mm in length (range = 325-400 mm). Other species captured included: 23 suckers, 1 smallmouth bass, 1 walleye, and 2 carp. Many *northern* squawfish, suckers, and chiselmouth were gilled in the lead and wings of the net but were not counted in the final tally. A smaller mesh net would be advised in further study of this gear.

Eight beach seine hauls yielded 10 juvenile northern squawfish. Other juvenile fish caught included: 471 American shad, 11 bass (both largemouth and smallmouth), and 12 yellow perch. One adult carp and 6 adult suckers were also caught in the beach seine. All fish were released back into the reservoir with the exception of the American shad which were used as bait for the longline.

## Handling Mortality of Incidental Species

There was considerable mortality in the gillnets. Five of nine steelhead were dead after capture during the summer sampling season. After an overnight set in the McNary section six walleye mortalities were removed from one net. Many channel catfish had to have pectoral and dorsal fin spines removed in order to facilitate release from the gillnet. Also, many suckers were disfigured upon removal from this gear. American shad tended to float after release and most appeared to be moribund. Other mortalities occurred, especially in overnight sets, however, precise records on mortality were not kept.

White sturgeon, channel catfish, yellow perch, and American shad were the only game or food species caught by longline. All eight yellow perch caught by longline were dead at capture; this species in every case swallowed the hook completely. Few channel catfish caught by longline were moribund (heavy bleeding) on capture and one of 71 sturgeon was dead on capture. Both species tended to be hooked in the outer mouth parts and could thus be released in relatively unharmed condition (Table C-11).

Live holding experiments with these two species captured on the longline are summarized in Table C-11. In the summer, two of 40 sturgeon and 3 of 22 catfish died on holding. All mortalities occurred during the first day of capture and most of these were bleeding from

Table C-11. Results from liveholding observations with longline captured Channel catfish and White sturgeon from June-November 1989 and hooking location of these two species captured on longlines from September-November 1989.

| SPECIES | HELD | MORTALITY | DAYS HELD | % MORTALITY |
|---|---|---|---|---|
| Channel catfish | 38 | 4 | >3 | 10.5 |
| White sturgeon | 50 | 2 | >3 | 4.0 |

HOOK LOCATION-

| | Channel catfish | | White sturgeon | |
|---|---|---|---|---|
| | # | % | # | % |
| Lower lip | 6 | 15.4 | 12 | 66.7 |
| Upper lip | 22 | 56.4 | 1 | 5.6 |
| Swallowed | 7 | 17.9 | 1 | 5.6 |
| Fowl hooked | 3 | 7.7 | 3 | 16.7 |
| Lower mouth | 0 | 0.0 | 1 | 5.6 |
| Roof of mouth | 1 | 2.6 | 0 | 0.0 |
| Total observed | 39 | | 18 | |

removal of swallowed hooks. During the fall, ten white sturgeon were held without an incidence of mortality and one of 16 channel catfish died while being held in the net pen. This catfish had swallowed the hook and died within 4 hours of capture. Due to the low incidence of mortality it is not clear if water temperature had an affect on the mortality rates or not. Obviously the primary variable in determining survival rate of released fish from the longline was hooking location.

A summary of hooking locations for these species during the fall sampling period is also included in Table C-11. Both white sturgeon and channel catfish tended to be caught in the outer mouthparts which allowed for ease in hook removal and minimal damage to the fish. However, almost 18% of the catfish swallowed the hook. This is usually damaging to the fish and we found that the survival rates of these fish are much lower than fish hooked in other locations. Only 5.6% of the sturgeon swallowed the hook.

## Catch Comparisons Between Gear Types

### Longline vs. Purse Seine

CPUE for longlines and purse seines fished on the same day, the same location, and same relative time of day are compared in Table C-12. Purse seines were set directly before or after fishing one or two longlines in a particular area to determine if one or the other gear type had a higher catch rate. Since it takes roughly the same amount of effort (not including fishing time) to set and pull either a 50 hook longline or a purse seine, catch per set was compared in order to determine catch efficiency relative to actual effort (catch per set). The longline had a much higher catch rate using this comparison (Table C-12).

The most important observation within this data is the consistency of catching northern squawfish with the longline. In ten out of eleven locations, the longline was able to catch at least one squawfish, whereas, in only three out of eleven instances the purse seine was successful in capturing a squawfish. It should also be noted that when the longline was successful and the purse seine was not, 15 out of the 22 squawfish captured on the longline were taken above 30 feet in depth, which is the fishing depth of the purse seine. This might indicate some gear avoidance from the purse seine by the squawfish.

Table C-12. Catch comparison for longlines and purse seines fished on the same date and in the same location on the Columbia river, 1989.

| | Date | Area and Description | LONGLINE Number of Sets | Set hours* | SQF catch | PURSE SEINE Number of Sets | Set hours | SQF catch |
|---|---|---|---|---|---|---|---|---|
| 1) | 7/26/89 | McNary spillway -no current | 1 | 3.00, | 18 | 1 | 0.50 | 3 |
| 2) | 8/26/89 | McNary spillway -no current | 1 | 4.13 | 4 | 1 | 0.50 | 0 |
| 3) | 9/6/89 | McNary spillway -no current | 2 | 4.65 | 1 | 1 | 0.50 | 0 |
| 4) | 9/12/89 | Irrigon channel -off hatchery -some current | 2 | 9.45 | 4 | 3 | 1.42 | 0 |
| 5) | 9/15/89 | McNary spillway -no current | 2 | 7.04 | 5 | 3 | 0.75 | 0 |
| 6) | 9/27/89 | McNary forebay -off McNary park -some current | 1 | 3.60 | 3 | 1 | 0.25 | 0 |
| 7) | 9/27/89 | McNary forebay -off WA shore -some current | 1 | 2.24 | 0 | 3 | 0.67 | 0 |
| 8) | 9/28/89 | McNary forebay -off McNary park -some current | 2 | 4.88 | 1 | 2 | 0.42 | 1 |
| 9) | 9/28/89 | McNary forebay -off WA shore -some current | 2 | 5.12 | 3 | 2 | 0.34 | 0 |
| 10) | 9/29/89 | McNary forebay -off McNary park -some current | 1 | 1.44 | 1 | 1 | 0.17 | 0 |
| 11) | 9/29/89 | McNary forebay -at lock entrance -no current | 1 | 3.52 | 5 | 3 | 0.51 | 2 |
| TOTAL | | | 16 | | 45 | 21 | | 6 |
| Mean catch per set | | | | 3.455 | | | 0.379 | |

*Assuming a 50 hook longline set.

**Longline vs. Bottom Gillnets**

Comparisons between longlines and bottom gillnets are more easily developed. Longlines and bottom gillnets were often fished side by side during the summer and fall sampling seasons. After searching through all of the data, 47 instances were found in which both longline and gillnet sets were made in the same location on the same day and over approximately the same time period of the day (Table C-13). No overnight sets were included and only sets made at similar depths were compared. In these 47 circumstances, quite often two *or* three gillnets were fished beside one longline of approximately 50 hooks and less often two longlines of approximately 50 hooks were fished beside one bottom gillnet. Of the 47 circumstances, there were only 8 during which no northern squawfish were caught in either gear type.

Therefore, there were 39 instances where longlines and bottom gillnets were fished together and one or the other gear type was successful in capturing at least one northern squawfish. Of these 39 instances, which included a total of 74 bottom gillnet sets and 46 longline sets, a total of 49 northern squawfish were taken in the gillnets and 163 northern squawfish were taken on the longlines. In 18 of 39 of these instances, the longline caught one or more northern squawfish while the bottom gillnets caught none. And on only 3 occasions did the bottom gillnets catch one or more squawfish while the longlines fishing the same area caught no northern squawfish.

Mean CPUE (catch per set) was calculated by summing the mean catch per set of each of the 47 observations for both the longline and gillnet and dividing by 47. The longlines averaged a catch per set of about 4 times higher than the bottom gillnets for these 47 observations, where these two gear types were fished simultaneously (Table C-13).

A diurnal distribution of catch per hour was calculated for all gillnets, both surface and bottom, and all longlines, assuming 50 hook sets, by averaging CPUE over the hours in a day that each piece of gear was fished (Figure C-8). Only sets under six hours were included in this analysis. This figure shows that the best catch rates for both gear types occur near dawn and dusk and there is a definite lull in catch rates in the early afternoon for longlines and later in the afternoon for gillnets. It is noteworthy that hourly fluctuations in catch rates paralleled one another for both gear types during a typical day.

Table C-13. Catch comparisons for longlines and bottom gillnets fished simultaneously during the same date, time, depth, and specified location within a transect on the Columbia river, 1989. (SQF = Northern squawfish) .

| | Date | Transect | LONGLINE Number of Sets | Set hours* | SQF catch | BOTTOM GILLNET Number. of Sets | Set hours | SQF catch |
|---|---|---|---|---|---|---|---|---|
| 1) | 5/22/89 | McNary tailrace | 1 | 3.8 | 5 | 1 | 2.5 | 2 |
| 2) | 5/22/89 | McNary tailrace | 1 | 3.3 | 1 | 1 | 1.8 | 0 |
| 3) | 5/25/89 | McNary tailrace | 1 | 4.0 | 0 | 1 | 2.0 | 0 |
| 4) | 6/01/89 | Paterson | 1 | 2.5 | 6 | 1 | 2.0 | 0 |
| 5) | 6/01/89 | Irrigon | 1 | 5.0 | 2 | 1 | 2.3 | 0 |
| 6) | 6/02/89 | Paterson | 1 | 1.5 | 1 | 1 | 1.5 | 0 |
| 7) | 6/02/89 | Paterson | 1 | 3.0 | 1 | 1 | 2.0 | 0 |
| 8) | 6/02/89 | Irrigon | 1 | 4.5 | 0 | 1 | 2.0 | 0 |
| 9) | 6/07/89 | Arlington | 1 | 2.0 | 0 | 1 | 2.0 | 0 |
| 10) | 6/07/89 | Arlington | 1 | 3.5 | 1 | 1 | 2.0 | 0 |
| 11) | 6/08/89 | Arlington | 1 | 3.1 | 2 | 2 | 4.0 | 1 |
| 12) | 6/14/89 | John Day | 1 | 4.5 | 0 | 1 | 3.0 | 2 |
| 13) | 6/14/89 | John Day | 1 | 4.8 | 0 | 1 | 2.0 | 1 |
| 14) | 6/15/89 | John Day | 1 | 4.4 | 0 | 1 | 1.9 | 0 |
| 15) | 6/15/89 | John Day | 1 | 4.0 | 0 | 1 | 2.3 | 0 |
| 16) | 6/15/89 | John Day | 1 | 2.2 | 2 | 1 | 2.0 | 0 |
| 17) | 6/19/89 | McNary tailrace | 1 | 1.8 | 1 | 1 | 2.0 | 1 |
| 18) | 6/21/89 | McNary tailrace | 2 | 10.9 | 13 | 2 | 4.8 | 2 |
| 19) | 6/27/89 | Paterson | 1 | 1.0 | 3 | 1 | 2.1 | 0 |
| 20) | 6/27/89 | Paterson | 1 | 2.3 | 2 | 1 | 2.0 | 0 |
| 21) | 6/28/89 | Irrigon | 1 | 1.8 | 1 | 1 | 2.0 | 0 |
| 22) | 7/05/89 | Arlington | 1 | 4.3 | 4 | 2 | 4.0 | 0 |
| 23) | 7/05/89 | Arlington | 2 | 5.5 | 14 | 2 | 4.2 | 0 |
| 24) | 7/06/89 | Arlington | 1 | 5.5 | 3 | 4 | 8.3 | 2 |
| 25) | 7/06/89 | Arlington | 1 | 5.5 | 5 | 2 | 4.2 | 5 |
| 26) | 7/07/89 | Arlington | 1 | 4.5 | 4 | 2 | 4.0 | 1 |
| 27) | 7/13/89 | John Day | 1 | 3.3 | 0 | 1 | 2.0 | 0 |
| 28) | 7/14/89 | John Day | 1 | 6.0 | 1 | 4 | 8.4 | 7 |
| 29) | 7/17/89 | McNary tailrace | 2 | 8.0 | 17 | 4 | 8.0 | 1 |
| 30) | 7/25/89 | Irrigon | 1 | 3.0 | 2 | 2 | 4.0 | 1 |
| 31) | 7/26/89 | McNary tailrace | 1 | 3.0 | 18 | 1 | 3.0 | 1 |
| 32) | 7/28/89 | Irrigon | 1 | 3.5 | 2 | 4 | 8.0 | 0 |
| 33) | 7/28/89 | Irrigon | 1 | 4.2 | 0 | 4 | 8.0 | 0 |
| 34) | 8/01/89 | Arlington | 1 | 3.3 | 1 | 4 | 8.1 | 2 |
| 35) | 8/02/89 | McNary tailrace | 1 | 4.8 | 5 | 4 | 8.0 | 0 |
| 36) | 8/02/89 | McNary tailrace | 1 | 2.3 | 7 | 3 | 6.0 | 5 |
| 37) | 8/07/89 | John Day | 2 | 6.3 | 1 | 4 | 8.1 | 2 |
| 38) | 8/07/89 | John Day | 1 | 3.3 | 3 | 3 | 6.0 | 1 |
| 39) | 8/08/89 | John Day | 1 | 3.5 | 4 | 4 | 8.0 | 0 |
| 40) | 8/25/89 | McNary tailrace | 1 | 4.1 | 4 | 1 | 2.3 | 1 |

more..

Table C-13 continued.

| | Date | Transect | LONGLINE Number of Sets | Set hours* | SQF catch | BOTTOM GILLNET Number of Sets | Set hours | SQF catch |
|---|---|---|---|---|---|---|---|---|
| 41) | 9/06/89 | McNary tailrace | 2 | 4.6 | 1 | 1 | 2.3 | 0 |
| 42) | 9/15/89 | McNary tailrace | 2 | 7.0 | 5 | 1 | 2.3 | 0 |
| 43) | 9/28/89 | McNary forebay | 1 | 2.4 | 0 | 1 | 2.3 | 4 |
| 44) | 9/29/89 | McNary forebay | 1 | 3.5 | 5 | 1 | 3.3 | 0 |
| 45) | 10/02/89 | McNary tailrace | 1 | 1.9 | 0 | 1 | 2.0 | 0 |
| 46) | 10/04/89 | McNary tailrace | 2 | 5.8 | 6 | 1 | 2.0 | 1 |
| 47) | 10/05/89 | McNary tailrace | 2 | 7.7 | 10 | 1 | 2.0 | 6 |
| Total | | | 55 | 190.2 | 163 | 85 | 176.5 | 49 |
| Mean catch per set | | | | 2.755 | | | 0.627 | |

*Assuming 50 hook longline set.

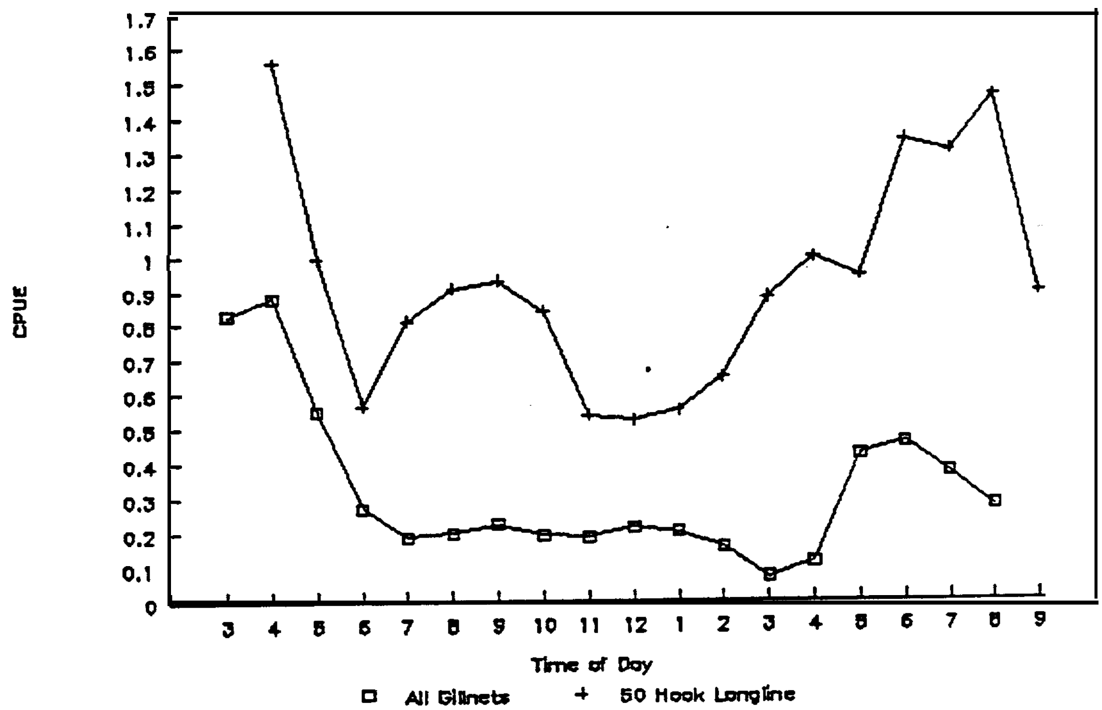



Figure C-8. Mean catch per hour by time of day for all gillnets and longlines set in the John Day reservoir, 1989. (Sets over 6 hours have been omitted.) Gillnet CPUE = catch per net hour, Longline CPUE = catch per 50 hook longline per hour.

### Length Frequency Comparisons Between Gear Types

Length frequency histograms are provided in Figure C-9 for the fishing effort for this project. The longline caught a wider range of size classes, and both longlines and gillnets tended to target predacious sized (>250 mm) northern squawfish. The mean size was 348 mm for the gillnets and 374 mm for longlines. The mean was 365 mm for the lake trap fished in the McNary tailrace area.

Beamesderfer and Rieman (1988) also showed that gillnetting, trapnetting, electrofishing, and angling tend to target predacious size northern squawfish (Figure C-10). However, Dell et al. (1975) showed that Merwin traps, Pennsylvania traps, and beach seining tend to target squawfish under 250 mm (Figure C-11).

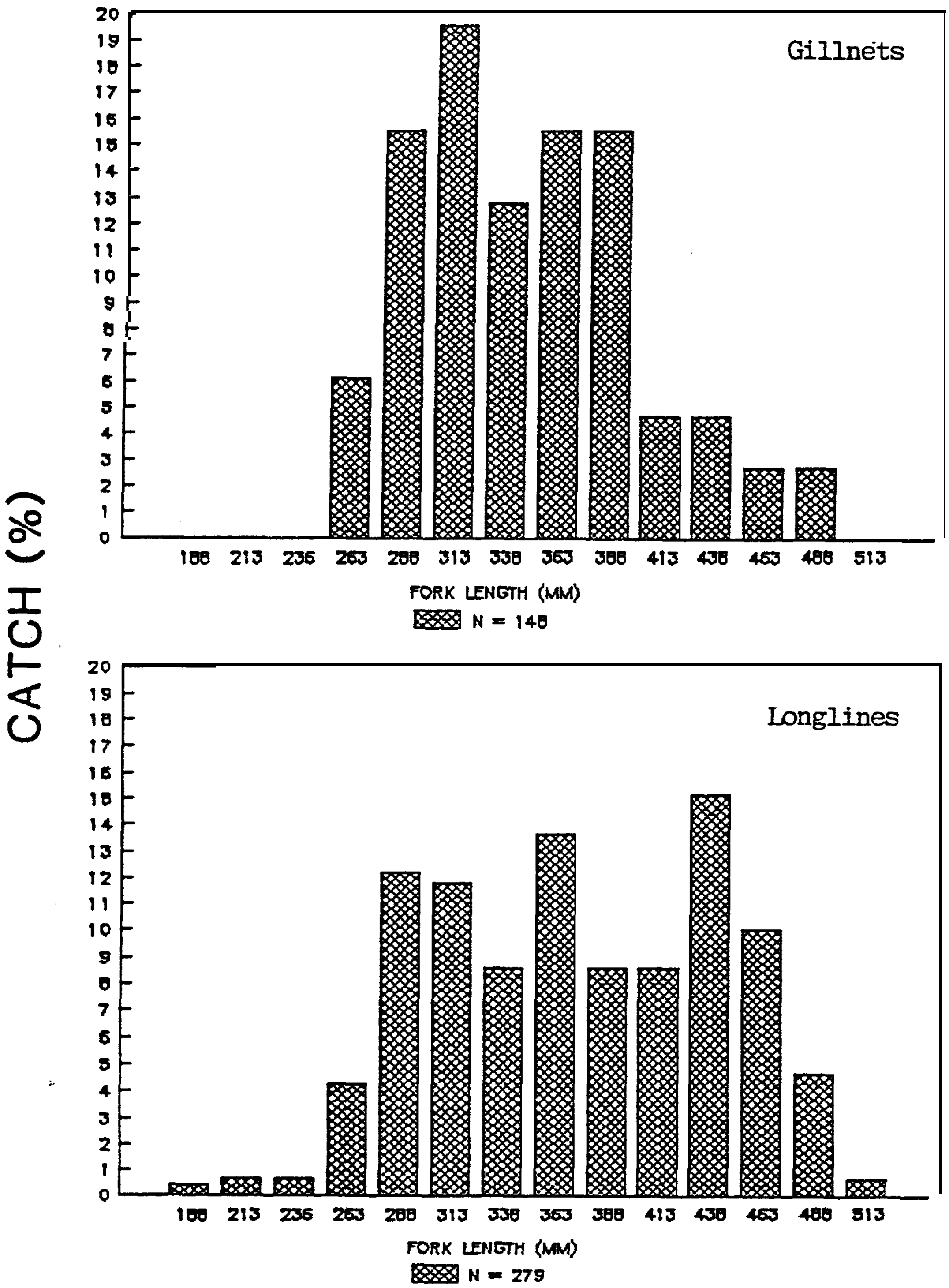



Figure C-9. Length frequency distribution for longline and gillnet catches of northern squawfish in the John Day reservoir, 1989. (x = 348 mm for gillnets and x = 374 mm for longlines)

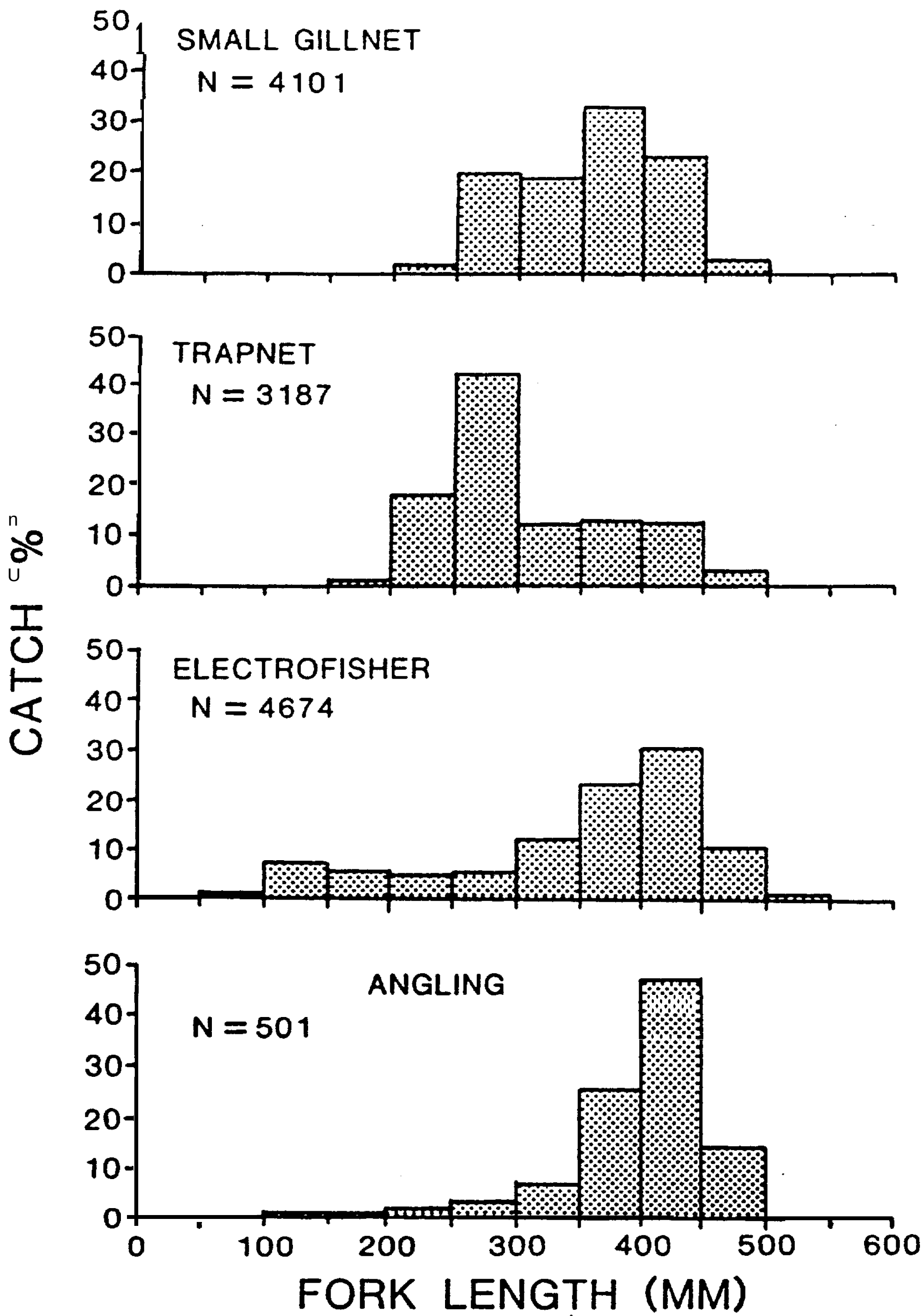



Figure C-10. Length frequency distributions of northern squawfish collected in John Day reservoir by four gears from April through June, 1983-86 (Beamesderfer and Rieman, 1988).

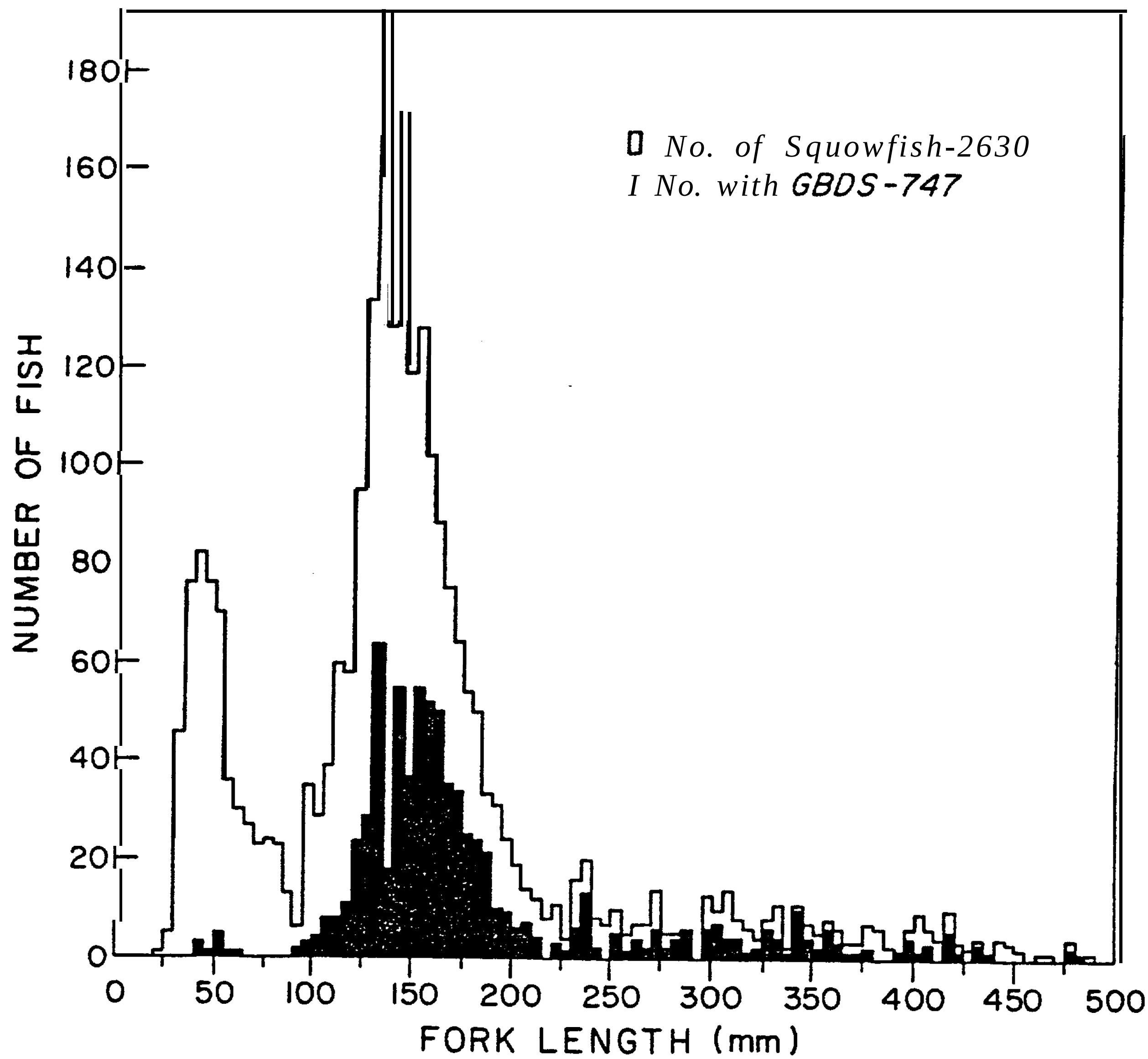



**Figure C-11.** Length frequency of squawfish with and without gas bubble disease symptoms caught using Merwin traps, Pennsylvania traps, and beach seining in mid-Columbia reservoirs, 1974 (Dell et al., 1975).

## DISCUSSION

Based on the results of data collected during the summer and fall of 1989; longlining has the greatest potential as a commercial fishing technique for northern squawfish of all gears tested. The baited longline had a low incidental catch rate, low mortality rate of incidentally caught species, and a high catch rate for northern squawfish. It is also highly adaptable to boats already in use on the reservoirs in this area and can be fished with one or two man crews. Hand operated equipment is very efficient and initial investment in the gear can be minimal. Also, fishermen with little expertise in using the longline as a capture method should achieve relatively high catch rates of northern squawfish.

Smolts work well as bait but availability for broad use may be impractical or illegal. American shad may work well, but they must be collected in the fall and stored over winter. It is not known how well frozen shad will perform in the spring and early summer as a bait source. Crayfish seem to work quite well, but baiting and debaiting is very difficult and time consuming.

Hook type used on the longline is also very important. The smaller wire hooks did the least damage to the fish and were easiest to bait and debait. The Kahle horizontal hook seemed to have a higher catch rate than any other hook types.

Longlines need to be fished at all depths because northern squawfish tend to be located throughout the water column, or at least catch rates indicated that they are feeding at all depths. Fishing surface to bottom also allows the fisherman to easily mark the longline with a float on the surface so that recreational anglers can identify the location of the submerged line. It is also indicated that fishing should be done during the morning and evening hours since catch rates tend to fall during midday.

We encountered sport fishery gear entanglement often enough that this could be a problem with an intensive fishery. Consideration should be given to times and areas of fishing, length of groundline per set, flotation methods, and marking methods in design of regulations.

Gillnetting presents many of the problems initially anticipated. However, the high incidence of undesirable fish (suckers, American shad, carp, etc...) could be an asset if a multi-species removal fishery were to be implemented. Additionally, we found that bottom-fished gillnets require a good deal of mending. Sticks, rocks, and incidental species produce damage to the web at a rate higher than anticipated. Due to man-hours needed for repair, it may be less expensive to buy new gillnets as older nets degenerate, rather than mend old ones. However, either alternative to the problem of gear damage may be relatively expensive.

Purse seining has been disappointing in its yields, particularly since gear and equipment costs were relatively high. Much of the reservoir area where northern squawfish occur is less than 30 ft deep, the minimum depth of our gear. A shallower seine could be built, yet northern squawfish might then tend to swim beneath it. Multi-gear testing near McNary dam suggests that northern squawfish may see and avoid the seine. On several occasions, longlines yielded good CPUE on northern squawfish, and these fish were above the effective fishing depth of the purse seine, yet subsequent purse seine catches were quite low over the same area.

Our purse seine catches averaged 5 fish per set at best, in the McNary spill basin. Previous purse seining for squawfish by U.S. National Marine Fisheries Service was a good deal more successful, particularly in Snake River reservoirs; catches up to several hundred squawfish per set were made, although more usually success was of a lower order of magnitude (Table C-14). NMFS used a larger seine (600 feet long) than ours (D. Miller, USNMFS, personal communication), and may have been fishing areas more suitable to successful purse seining. We found from longlining, gillnetting, and other observations that squawfish seem to be most abundant in water too shallow or too turbulent (or both) for purse seining.

Purse seining is normally an effective technique for migrating, schooling pelagic species. Dense schools of northern squawfish are commonly observed at the dams (e.g., McNary turbine outlets). Physical and safety conditions may rule out purse seining in a commercial mode near the dams; however, control of hydropower water output could be coordinated with test purse seining activities in order to allow for fishing in areas where current is normally too strong or turbulent. The latter such circumstance should be fully considered to take maximal advantage of purse seining as a control technique.

Other than one two day test with a lake trap, we did not attempt to evaluate fixed trap gear in our field studies because so much work has been previously done with such gear. Furthermore, large traps seemed relatively unadaptable to small boats of the kind presently used for commercial fishing purposes in the Columbia river.

Two types of traps have been extensively tested on the Columbia river; Merwin traps and lake traps. The Merwin trap (see Lemier and Mathews, 1962 for a detailed description) is quite a large device, requiring pontoons, heavy ropes and anchors, as well as specialized boats and vehicles for movement and placement. Gearing up with boats and vehicles to fish such equipment would be quite expensive and each trap, including lines, pontoons, and anchors,

Table C-14. Catch-per-unit-effort of squawfish in experimental purse-seining in Columbia and Snake River reservoirs. Effort units are the left-hand numbers in each cell and are either seine-sets or seine-days depending on data source. Catch-per-seine-set is underlined once, and catch-per-seine-day is underlined twice.

| Location | Year | Effort Unit | Seine Dimensions | Total Effect - CPUE | | | | | | | | Data Source[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Apr. | May | June | July | Aug. | Sept. | Oct.-Dec. | All Months | |
| The Dalles cul-de-sac | 62 | Seine-set | 30' x 200' | | | 3-0 | | | | | | a |
| McNary forebay | 62 | Seine-set | 30' x 200' | | | | | | | 3-0 | | b |
| Little Goose tailrace | 74 | Seine-set | 600' | 6-5 | 8-7 | | 10-62 | 3-462 | | | | b |
| John Day forebay | 74 | Seine-set | 600' | 18-3 | 70-1 | 39-Tr | 34-Tr | 45-23 | 55-14 | 67-Tr | 328-6 | b |
| John Day tailrace | 74 | Seine-set | 600' | 2-Tr | | | | 10-2 | 14-2 | 17-1 | 43-1 | b |
| John Day tailrace | 75 | Seine-set | 600' | | | | 3-29 | 2-9 | 14-6 | 8-1 | 56-6 | c |
| McNary tailrace | 75 | Seine-set | 600' | | | 5-0 | 3-5 | 1-72 | | | 77-1 | c |
| Little Goose tailrace | 75 | Seine-set | 600' | 1-1 | 3-55 | | 3-104 | 6-84 | 4-22 | | 17-63 | c |
| Ice Harbor tailrace | 75 | Seine-set | 600' | | | | 4-18 | 3-26 | 1-50 | | 8-25 | c |
| Lower Granite tailrace | 76 | Seine-day | 600' | | 5-111 | 5-177 | 7-26 | 1-4 | | | | d |
| Lower Granite tailrace | 77 | Seine-day | 600' | | 1-112 | | | | | | | e |
| Little Goose tailrace | 77 | Seine-day | 600' | | 7-190 | 3-106 | | | | | | e |
| McNary spill basin | 89 | Seine-set | 25' x 350' | | | | 17-5 | 1-0 | 4-0 | | | f |
| McNary forebay | 89 | Seine-set | 25' x 350' | | | | | | 16-Tr | | | f |
| John Day pool | 89 | Seine-set | 25' x 350' | | | | 9-0 | | 5-0 | | | f |

1 Data Sources: a. LeMier and Mathews, 1962; b. Raymond et al., 1975; c. Sims et al., 1976, d. Sims et al., 1977; e. Sims et al., 1978; f. study.

is at least a $10,000 expense at present. Two men are needed to fish such traps and maintenance (web cleaning and mending) and observation requirements (to prevent pilfering of fish and/or vandalism) would be heavy.

However, Merwin traps have been found to be very effective for capturing northern squawfish at certain locations in the Columbia river reservoirs. Table C-15 summarizes Merwin trap catch data from previous studies. Shown here are average catches per trap day, by month. In many locations Merwin traps were not very effective, but in the cul-de-sac below The Dalles dam and the Palouse arm of Lower Monumental reservoir catch rates of several hundred northern squawfish per day were achieved. Highest catch rates were in June and July. It has previously been speculated that the high catch rates during these months are associated with migrational behavior accompanying spawning.

The use of Merwin traps or other large trapping devices, custom built for specific sites near dams, should be considered in an overall squawfish removal program. However, Merwin trapping is not readily adaptable for wide scale commercial use throughout the Columbia river. Such gear should probably be operated by state or federal agencies or perhaps on contract to such agencies with stringent operational requirements. This recommendation is due to at least two considerations. First, the best fishing opportunities are likely to be in restricted waters near hydroelectric dams, where safety considerations are paramount. Secondly, Merwin traps are quite effective on migrating adult salmonids. The traps must be emptied often and with care to avoid injury, mortality, and/or extensive migrational delays to these species.

Hook-and-line fishing, under various scenarios including longlining from small boats, sport bounties, and single or multiple hook angling from dams may be more cost effective than capturing squawfish with Merwin traps or similar devices. However, this question should be carefully considered after the various hook-and-line scenarios have been field tested for removal efficiency.

Smaller traps which can be operated from conventional Columbia river commercial fishing boats do not appear to be an effective alternative. Five years of extensive effort with lake traps (these devices are previously described in this report) indicated that the best success one might get with such gear in the John Day reservoir is about 4 northern squawfish per trap day (Table C-16). This is less than the expected catch by a 50 hook longline set, according to our tests. A lake trap with its associated anchors, lines, etc. is a far more costly piece of gear

Table C-15. Catch-per-trap-day of squawfish by Merwin traps in experimental efforts in Columbia and Snake River reservoirs.

| Location | Year | Month | | | | | | | | | | | | All Months[2] | Data Source[3] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | | |
| The Dalles cul-de-sac | 61 | | | | | | | 482 | 177 | 230 | | | | 244 | a |
| The Dalles forebay | 61 | | | | | | | | | 30 | | | | 30 | a |
| The Dalles cul-de-sac | 62 | | | | 46 | 125 | 651 | 148 | 63 | 9 | | | | 146 | a |
| The Dalles forebay | 62 | | | | | 7 | | | | | | | | 7 | a |
| Drano Lake | 62 | | | | | | | | 22 | 16 | | | | 20 | a |
| McNary forebay | 62 | | | | | | | | | 72 | | | | 72 | a |
| Lower Monumental Palouse Arm | 74 | | ←23→ | | ←126→ | | 278 | 9 | ←14→ | | | ←8→ | | 54 | b |
| Lower Monumental Levey Landing | 75 | Tr | Tr | 2 | 17 | 36 | 30 | 90 | 10 | 12 | 3 | 1 | Tr | 17 | c |
| Lower Monumental Palouse Arm | 75 | 1 | Tr | 6 | 40 | 67 | 37 | 16 | 10 | 14 | | | | 21 | c |
| John Day forebay | 75 | | | | 1 | 4 | 2 | 5 | Tr | Tr | Tr | | | 2 | c |
| The Dalles forebay | 75 | | | | 2 | 8 | 8 | 2 | | | | | | 5 | c |
| Lower Monumental Palouse Arm | 76 | | | | 43 | 154 | 68 | 26 | | | | | | 81 | d |
| Lower Monumental mainstem | 76 | | | | 28 | 78 | 157 | 160 | 108 | | | | | 118 | d |

2 Weighted by days fished per month.

3 Data Sources: a. LeMier and Mathews, 1962; b. Raymond et al., 1975; c. Sims et al., 1976; d. Sims et al., 1977.

Table C- 16. Catch-per-unit-effort in experimental lake trap fishing in Columbia River reservoirs. Effort units are trap-days.

| Location | Year | Period Fished | Trap Days | CPUE | Data Source[1] |
|---|---|---|---|---|---|
| McNary tailrace | 82 | 7/17-12/31 | 16.1 | 1.4 | a |
| John Day pool | 82 | 5/24-7/16 | 15.7 | 1.8 | a |
| John Day tailrace | 82 | 7/17-12/31 | 22.5 | 0.8 | a |
| John Day forebay | 83 | 7/17-9/24 | 10.0’ | 3.4 | b |
| John Day tailrace | 83 | 4/24-9/24 | 124.6 | 1.9 | b |
| John Day, Irrigon | 83 | 7/17-9/24 | 49.9 | 1.7 | b |
| McNary tailrace | 83 | 4/24-9/24 | 154.0 | 2.4 | b |
| John Day forebay | 84 | 4/8-10/1 | 102.6 | 2.6 | c |
| John Day, Arlington | 84 | 4/8-10/1 | 88.8 | 3.1 | c |
| John Day, Irrigon | 84 | 4/8-10/1 | 100.0 | 1.4 | c |
| McNaryd tailrace | 84 | 3/25-10/1 | 94.3 | 1.9 | c |
| John Day forebay | 85 | 3/24-9/2 | 64.1 | 1.9 | d |
| John Day, Arlington | 85 | 4/7-9/2 | 113.9 | 0.7 | d |
| John Day, Irrigon | 85 | 4/7-9/2 | 104.8 | 1.7 | d |
| McNary tailrace | 85 | 4/7-9/2 | 87.5 | 1.0 | d |
| John Day forebay | 86 | 4/6-9/ 1 | 54.2 | 2.4 | e |
| John Day, Arlington | 86 | 4/6-9/ 1 | 84.0 | 1.4 | e |
| John Day, Irrigon | 86 | 3/23-9/1 | 90.3 | 0.7 | e |
| McNary tailrace | 86 | 3/23-9/ 1 | 68.0 | 0.7 | c |
| McNary tailrace | 89 | 11/1-11/3 | 2.0 | 4.0 | f |

1 Data Source: a. Willis et al., 1982; b. Nigro et al., 1983; c. Nigro et al., 1984; d. Nigro et al., 1985; e. Beamesderfer et al., 1987; f. 1989 squawfish study.

than a 50 hook longline and its related gear. Also, the ratio of incidental catch to squawfish catch would be higher in lake traps than on longlines. Even considering bait costs in a comparison, the lake trap is not a practical small boat technique compared with longlining.

During the early phases of our investigation, one of our contacts (M. Dell, Grant County P.U.D., *personal* communication) suggested that beach seining had been an effective technique for capturing northern squawfish in mid-Columbia reservoirs. We reviewed these investigations, but found that most of the fish caught by beach seining were less than the predacious size of 250 mm (Dell et al., 1975). Because of this and the recommendation against the likelihood of success in the John Day reservoir by J. Elliot (ODFW, personal communication) who had previously tested such gear in the John Day reservoir, we did not consider beach seining for testing other than for longline bait collection.

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**REPORT D**

**Columbia River Ecosystem Model (CREM) -- Modeling Approach for Evaluation of Control of Northern Squawfish Populations Using Fisheries Exploitation**

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**FINAL** REPORT

# COLUMBIA RIVER ECOSYSTEM MODEL (CREM) --- MODELING APPROACH FOR EVALUATION OF CONTROL OF NORTHERN SQUAWFISH POPULATIONS USING FISHERIES EXPLOITATION

Services Contract to BPA Project No. 82-012:
Interstate Cooperative Agreement 86-012

## Introduction

The Columbia River Ecosystem Model (CREM) is a differential equation model and an associated computer simulation program. The CREM simulates predator-prey interactions which occur as juvenile salmonid fishes migrate downstream through impoundments of the Columbia River. The model and simulator are intended to project the mortality of juvenile salmonids due to the complex interactions occurring during the downstream migration. A summary of the CREM is contained in appendix B of Fickeisen et al. 1989.

This report is to document accomplishment of the objectives and tasks required in the above referenced contract, as follows:

(1) documentation of the Columbia River Ecosystem Model (Objective 2);

(2) documentation of past analyses of juvenile salmonid mortality which were performed with the aid of CREM (Objectives 2 & 3);

(3) modifications of CREM intended to expand its analysis capabilities (Objective 1); and

(4) analysis of predator fishery effects using the modified CREM, and documentation of the model and analysis (Objective 3).

The first two of these items is fulfilled by the manuscript (draft for scientific publication) Bledsoe et al. (1990). This manuscript contains a detailed description of the methods used in the CREM, Ver. 1, and the results of analyses of the effects of residence time, reservoir temperature, uncertainty in the functional response curve, migration timing and intensity and uncertainty in the residence time on mortality due to predation in five species of juvenile salmonids. The manuscript is appended (Appendix D-1) to this report.

# CONTENTS

The modifications of the CREM called for by item 3 concerned expansion to provide for the following considerations'[1]:

(1) effects of a predator fishery on juvenile mortality, through reduction of the predator population (Tasks 1.1, 1.3);

(2) effects of dynamically variable predator population distribution throughout the reservoir (Task 1.2);

(3) error bounds or confidence'limits on predicted mortalities due to stochastic variation or uncertainty in model parameter values and driving functions (Task 1.7);

(4) effects of population dynamics and growth in response to ingested food (energetics) of predator populations (Tasks 1.4, 1.5);

(5) projection of mortality time series over multiple years (Task 1.8); and

(6) a design to allow the CREM to project mortalities over a system of connected reservoirs, rather than a single reservoir (Task 1.9);

(7) provision for user friendly specification of input parameters and output graphics (Task 1.10).

These modifications were approached incrementally by development of Version 2 of the CREM in a series of sub-versions. Item 4, the provision of population dynamics and energetics, is a much more complex enhancement of CREM, Ver. 1, than is items 1 - 3. Further, there will be frequent analyses of reservoir situations, both hypothetical and actual, for which the consideration of detailed population dynamics and energetics will not significantly change the projected mortalities. This will occur nearly any time that analyses over only one or a few seasons are desirable, since the effects of population dynamics and energetics, except in extreme cases, will be in terms of gradual changes in the age structure and spatial distribution of the predators. Consequently there are two advanced versions of the CREM which result from this contract. User friendly input and graphic output (item 7) has been provided for both versions and both are amenable to multi-reservoir applications under the design developed for item 6.

Version 2.04 incorporates items 1 - 3 and 5, above, and does not consider a dynamic age structure or growth of predators; it is to be used for one to three year simulations of situations in

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[1] Note that a task numbered 1.6 was omitted from the contract.

which population dynamics are not expected to play a role. Note that the provision for multiple classes of predators in 2.04 does allow for consideration of age structure or a range of predator sizes, however these sizes are assumed not to be dynamic or fluctuating over time. Version 2.04 also may be utilized in multi-reservoir simulations, using the design to be described below.

Version 2.05 incorporates all five of the above items and can be configured for multi-reservoir simulations under the design for item 6. Since 2.05 requires a much larger and more complex set of parameter values, as well as five to ten times the amount of computer time to execute, it is desirable to utilize it only for **scenarios** in which its mechanisms will impact mortalities. These are, basically, simulations for two years or longer in which a selective fishery for predators will impact the predator age structure, or changes in prey densities will make a similar impact through energetic mechanisms.

These two advanced versions of the CREM simulator, 2.04 and 2.05, have been implemented in the **Fortran** programming language for MS-DOS based PC computers: they are designed for high speed 386 type **PC's** and require at least two Mb of hard disk storage. The implementation has been basically tested but has not been thoroughly exercised or utilized for analysis of the ecosystem. Following is a detailed description of the mathematical methods used to incorporate the five enhancements of CREM, Ver. 1.

Appendices D-2 and **D-3** contain the complete computer code, listings of input parameter files and sample output files.

Columbia River Ecosystem Model, Version 2.04

**CREM** was originally designed to allow expansion to include such mechanisms as fishery mortality due to dynamic (i.e. fluctuating in time) fishery effort patterns and movement of segments of the predator population in response to assumptions about behavior patterns. The state variable approach, in which the dynamics of intensive (i.e. measured in units of concentration or density, numbers per unit area) variables are described by an ordinary differential equation (DE), is easily expandable through 1) the addition of terms to the original DE and 2) sub-division of the state variables into groups with an appropriate conservation condition. In the equations which follow, notational conventions follow those described in the Methods section of Bledsoe et al. (1990) and any variables not defined here may be found in that document.

Code listings, parameter files and example output from CREM, Ver. 2.04 are contained in Appendix D-2

Fisherv mortalitv

A driving function, ef, for fishing effort by predator type (which may be a size class), together with a parameter, pq, for gear catchability per population unit was incorporated in the catch equation for predator population rate of change:

$$\text{Dt[ Pn ]} = -\,(\text{pmt} + \text{pq ef})\ \text{Pn} \qquad 1$$

where Pn is predator population density and pmt is the natural mortality parameter incorporated in previous CREM versions. This is a modification of equation 6 of Bledsoe et al. (1990). Subscripts have been omitted from this equation to simplify the presentation (this convention will be continued throughout this report) , however pq is subscripted singly for predator type and ef is subscripted doubly for predator type and reservoir area. Since ef is a driving function, it is also time specific, allowing for specification of a time series of effort levels over a season. In order to accomodate multiple gear types, pq must be calculated by an effort standardization procedure prior to execution of CREM.

Predator population distribution

Dynamic movement of predators among areas of the reservoir is provided by addition of a migration mechanism in which an expected relative distribution of the predator population among reservoir areas is specified as an input parameter array, pPn, subscripted on predator type and reservoir area. Though not presently dynamic in time, the predator population relative distribution can be made so by simple changes to the simulator which make pPn a driving function rather than a parameter. Migration rates, mg, are an intermediate system variable (ISV) of the model calculated from pPn, the current predator population distribution array, Pn, and a rate of movement ISV. The rate of movement ISV, d3, is calculated from a maximum rate of movement parameter, pmg, and consideration of the distance between areas, as follows:

$$\text{d3} = \text{pmg} / (\sqrt{\text{pa}_i} + \sqrt{\text{pa}_j}) \qquad 2$$

where pa is the area in square meters of the reservoir location indicated by the subscript. Since the locations for inter-migration are adjacent, the average distance to be travelled will be proportional to the sum of the square roots of the areas. The actual migration coefficient can be calculated by

$$mg = d3\ Sw[\ Pn,\ 0.,\ pPn - Pn/tPn\ ] \qquad 3$$

where the function Sw is defined as

$$Sw[\ x,y,z\ ] = x \text{ if } z > 0. \qquad 4$$
$$y \text{ if } z <= 0.$$

and tPn is the total predator population in the entire reservoir. Equation 3 is appropriately subscripted so that mg is specific to predator type and two reservoir locations between which migration is taking place, i and j. This mechanism specifies that migration takes place into an area whenever the relative predator population of that area drops below the relative distribution specified by pPn. In order to balance this migration and provide for net conservation of numbers of fish, the conservation condition in equation 5 provides that the total migration from an area is equal to the sum of the migrations into other areas.

$$mg_{ii} = -\ S[\ mg_{ij}\ ] \qquad 5$$

where i is not equal to j in the summation. A detailed description of the use of this conservation condition in differential equation models may be found in Bledsoe and Van Dyne (1971).

Stochastic simulation for error bounds

A useful approach to provide for measures of uncertainty in the mortality projections of the CREM is to perform multiple simulations with one or more parameters and/or driving functions selected stochastically from a statistical distribution. This is called stochastic simulation (but is only one of several methods of conducting a stochastic simulation). The distribution may be due to measurement uncertainty, spatial or temporal variation or a possibly unknown combination of these. These simulations will result in multiple mortality estimates from whose statistical distribution can be inferred corresponding properties of mortality for the static conditions under which the simulations were performed. Interpretation of this interval, as opposed to point, estimate of mortality depends upon which parameters and driving functions were included in the stochastic simulation, and the origin of the distribution functions utilized. If, for example, only one parameter was varied across the multiple simulations then the variability in mortality estimates which results will represent only one component of total uncertainty. If little or no variation in mortality results then mortality is insensitive to that parameter. Stochastic simulation can be used as a type of sensitivity analysis in this way.

The above description of stochastic simulation would apply to the case in which variability in mortality between simulations, normally applicable to a single year or range of years, is to be studied. A second case involves the situation in which variablity within a year is to be studied. For example, we might want to study the effect of variability in flow regime between years, but the effect of variation in the predator functional response curve within a single season would probably be more relevant. Consequently, the discussion below describes methods for both types of stochastic simulation.

The means to perform stochastic simulation does not involve a change to the'model, which is the set of differential and algebraic equations chosen to describe the predation and migration processes, but simply to the computer program, or simulator, which numerically solves the equations and calculates mortalities as the logical consequences of the model. The necessary changes for CREM were incorporated by the addition of parameters for characteristics of the statistical distribution of model parameters.

For study of between time period variability, an indexing parameter, nrpt, and an outer loop was added to the simulator to control the number of repeated simulations to be performed. When nrpt is set to a value greater than one an input routine is called which reads a new parameter value. These values are generated in a file off line from the simulator in order that any parameter may be studied according to any distribution function and statistical parameter set.

For study of within time period variability, additional parameter values for the statistical parameters of the distribution to be used have been added to the input routine. For example, the parameter array psf describes the characteristics of sampled variability about the predator functional response curve; if psf(2) is zero, then a deterministic simulation results. If psf(2) is greater than zero, it is interpreted as the standard deviation of the functional response curve in the linear and asymptotic region. Provision for gaussian stochasticity in this region has been provided by addition of an appropriate pseudo-random number generator (subroutine gauss). In the constant or low prey density region of the curve, an empirical distribuion function (subroutine emp) has been provided; its chracteristics are given by parameters psf(4) through psf(13).

An example of use of the stochastic simulation capability is contained in Appendix D-1.

Miaration and fishina effort simulation

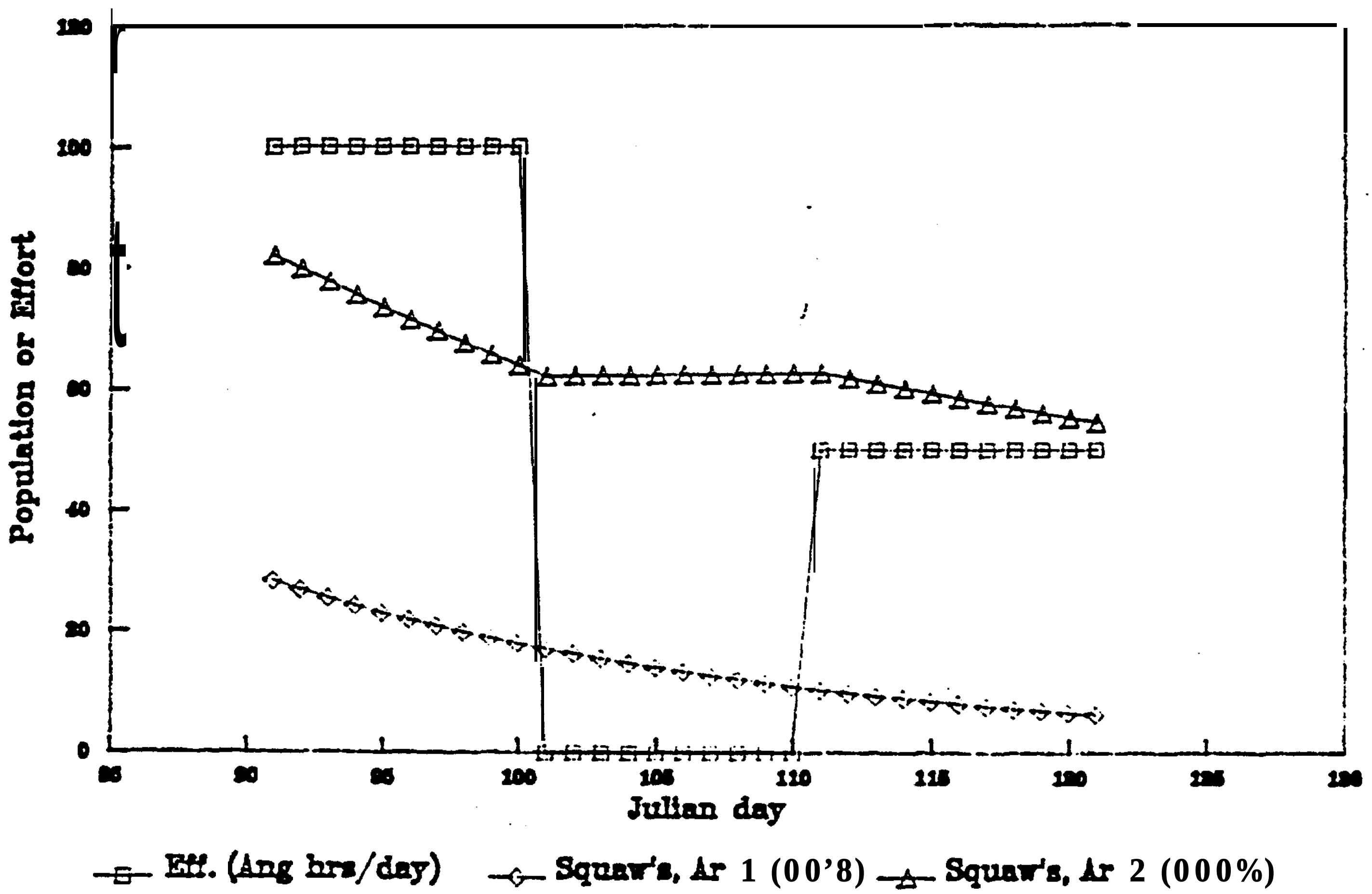
The CREM simulator was configured to checkout and demonstrate the above described mechanisms in a two area reservoir system. Catchability coefficients (pq) were- calculated to produce an average of twenty fish caught per hour of effort. This artificially high value was chosen so that the fishery effect would be clearly visible graphically. Effort level varying between zero and 100 hours/day in Area 2 only was implemented. Figure 1 shows the effect of the simulation of fishing effort with associated migration of predators toward a constant distribution across the two areas.

The fishing effort driving function starts at 100 hours/day for 10 days, followed by no (zero) effort for 10 days, and then by 50 hours/day for 10 days. During the first 10 days, the population dropped by approximately 20,000 fish, then stabilised approximately constant and finally dropped another 10,000 fish during the final 10 days of the simulation. At the same time the reduction in population of Area 2 induced a migration of fish from Area 1. This can be seen in Figure 1 as an exponential decrease in the Area 1 population. Because the population of Area 1 is small relative to Area 2, there is not a graphically noticeable increase in the Area 2 population during the time of zero effort, but printed output from the simulator revealed an increase of about 300 fish. The decay of population in Area 1 did not change over the simulation, in spite of the changing effort, because the migration rate (pmg = .05 l/da m) was constant, based on estimates of average movement of squawfish.

Columbia River Ecosystem Model, Version 2.05

Compensatory response of predators to changes in their population size, structure or spatial distribution by management actions is assumed to be caused by density or energy status dependent behavioral and/or physiological effects within the population. The study of such responses requires a mechanistic model which relates population structure (over long time periods within the life span of the animal) to its energy status. Dynamic energetics models have been developed for fish populations by Kitchell and others. Bledsoe and Megrey (1989) have extended these to a population context in which the animals energy status may be related to population mortality and fecundity. That paper describes completely the mathematical methods which have been incorporated into CREM, Ver. 2.05.

Figure 1. Squawfish population. dynamics resulting from a two area test simulation incorporating a predator migration mechanism and variable fishing effort (CREM Ver. 2.04).



Modifications to the model fell into two classes: addition of predator energetics and predator multi-year populaton dynamics. The energetics equation describes the rate of change of weight of a predator as a sum of assimilated food minus metabolic and reproductive losses. The differential equation added to subroutine der of the simulator is

$$. \ . \ . \ . \ . \quad Dt[\ Pw\ ] = pae\ S[rc] - pwl\ qw\ Pw^{pw2} - Dt[Eg] \qquad 6$$

where Pw is predator weight by type and resevoir area, pae is assimilation efficiency, rc is the rate of consumption of food, pwl and pw2 are respiration rate parameters, qw is an ISV describing respiration rate dependence on temperature and Eg is the egg density. Dt[Eg] gives the time rate of egg production and is calculated as the difference between assimilated energy plus respiration and the Von Bertanffy growth rate (see Bledsoe and Megrey 1989).

An assumption of the model is that the predators will grow according to parameters of a Von Bertalanffy growth curve provided they have sufficient food. Assimilated energy in excess of that required for growth is assumed to go into reproduction. The only variable food source assumed in the model is juvenile salmonids, although this is easily modified. The dynamics of the model will reflect increasing fecundity and, consequently, long term population growth to the extent that the predators have an abundant food resource in juvenile salmonids. Conversely, denying them this resource will result in population contraction.

Multi-year population dynamics is relatively simple, involving accounting for graduation of age classes at the end of a season and conversion of the surviving fraction of reproductive products (eggs) to age 1 animals. Because the squawfish predators are relatively long-lived (more than 15 years) and because only the older, larger fish are responsible for predation, the simulator does not calculate energetics for the younger age classes. (Energetics calculations for the non-predator ages would require specification of a food resource, which has not been researched.) The simulator does keep track of their numbers from year to year with annual survival rates assumed constant (parameter pnw) and over-winter weight loss (parameter pww). Population dynamics accounting has been incorporated in subroutine grad.

Appendix D-3 contains the program listing, input data and example output from Ver. 2.05.

## Complex area simulation with age structure and bioenergetics

A complex area structure for John Day resenroir was configured for simulation of sguawfish predation. The objective of the simulation was to provide a tool for investigation of relative mortality rates in different resenroir areas, in response to varying predator population densities and juvenile salmon migration routes. Data for configuration of the multi-area simulator is expected to begin to be available from fishery research beginning during the 1990 field season. The simulator is specifically capable of **considering the** spatial distribution of sguawfish fisheries planned during 1990. The five areas considered were as shown in Table 1.

Table 1. Area structure for multi-area simulation of fishery and predation processes in John Day reservoir. The columns labeled "Probability of **migration"** give the connectivity of the areas and the assumed probability that a smolt departing one area will enter an adjacent area.

| No. | Description | Area (ha) | Probability of migration 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| 1 | **Tailrace** | 4.6 | -- | .4 | .5 | .1 | .0 |
| 2 | Reservoir | 1660. | .0 | -- | .2 | .2 | .6 |
| 3 | Channel | 210. | .0 | .2 | -- | .2 | .6 |
| 4 | Nearshore | 210. | .0 | .2 | .2 | -- | .6 |
| 5 | **Forebay** | 23. | .0 | .0 | .0 | .0 | .0 |

The numbers in the columns labeled "Probability of migration" are called an adjacency matrix (see the simulator data file listing in Appendix D-2 ). They describe in mathematical terms the connectivity of the sub-areas into which the reservoir is divided. The first row of numbers indicates that juveniles may migrate from Area 1 into either of Areas 2, 3 or 4, but not Area 6. The values give the relative proportions of the downstream migrants which move into the respective areas. The second row similarly describes the proportion moving out of the main Reservoir (Area 2) into the Channel, Nearshore area or **Forebay.** The adjacency matrix approach allows configuration of any desired connectivity for simulation of complex sub-area structures in a reservoir. Though this example shows a single adjacency matrix common to all salmonid species, the matrix may be made specific to the species so that different migration routes may be assumed for each.

Based on the above areas structure, a simulation was performed for 1985 conditions in John Day reservoir. CREM Ver. 2.04 was used for the simulation since effects of age structure were not a part of the objectives. Table 2 contains the mortalities predicted by salmonid type and area, taken from the final page of the output listing (Appendix D-2 ). These are generally comparble with the mortalities contained in Table 1 of the document describing a two area simulation in Appendix 1. Detailed specifications for the simulation can be found in the output listing in Appendix D-2. The listing also contains further output information such as the time series of 10-day consumption rates per predator (output block labelled "Per capita consumption by area) and total passage numbers (row labelled "TotPsg").

Table 2. Simulated mortality as fraction and number consumed (parentheses, $x10^6$) for five salmonid types in the five areas described in Table 1.

| | Salmonid type | | | | |
|---|---|---|---|---|---|
| Reservoir Area | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
| Tailrace | 0.019 (0.219) | 0.002 (0.019) | 0.002 (0.004) | 0.003 (0.000) | 0.002 (0.004) |
| Reservoir | 0.263 (3.003) | 0.022 (0.118) | 0.029 (0.044) | 0.043 (0.005) | 0.028 (0.052) |
| Channel | 0.158 (1.804) | 0,042 (0.231) | 0.055 (0.086) | 0.085 (0.011) | 0.055 (0.104) |
| Nearshore | 0.141 (1.609) | 0.051 (0.275) | 0.064 (0.098) | 0.095 (0.012) | 0.063 (0.119) |
| Forebay | 0.015 (0.173) | 0.006 (0.035) | 0.009 (0.013) | 0.018 (0.002) | 0.009 (0.016) |
| Total | 0.597 | 0.123 | 0.159 | 0.243 | 0.157 |

Simulator structure, Ver. 2.05

A detailed description of parameter values and their units of measurement is included with the input parameter file (file **'crem.dat',** Appendix D-3). This allows easy reference to parameter definitions when changes are made with a data editing program. The parameter file in many cases defines only the first value in a parameter array; the simulator detects this and assumes that other values which must be defined in the array will have the same value. Alternatively, the parameter file may define all values in the array independently by including the appropriate subscript values in the columns **labelled '1st', '2nd'** and **'3rd'.** The first subscript refers to area, the second to species (either **salmonid** species or predator age group, as appropriate). The third column refers to an arbitrary numbering used for some parameter arrays, such as the break points in the empirical distribution function describing stochastic variation in the functional response curve.

Parameters of a specific simulation are given by the file **'simpar.dat'** (Appendix D-3). These values are echoed to the output file and identified there.

A set of standard output from a simulation is contained in Appendix D-3. After echoing model and simulation parameters the output file contains a series of blocks of model output values in which each block corresponds to a specific simulated time, one day in the.example of Appendix D-3. Each block consists of the following identified sections:

Time and driving function values

Prey species density by area and total passage to date

Predator species density by age and area

Total consumption of prey by species, area and predator species

Fractional mortality to date by prey species and area, with total reservoir mortality (identified by letter **'T'**)

Per capita consumption of prey for this time period by predator age group and reservoir area

Adult predator lengths (mm) by predator age group and area

Number of eggs produced to date

Number of juvenile predators in each age group

Lengths of juvenile predators by age group

At the end of a simulated year the number of juvenile age groups is reported after determination of whether sufficient growth has occurred to promote one or more into the adult predator class. A model parameter, plt, specifies the size break in mm for this to occur. Finally, the area1 distribution of predator numbers is reported. For a multi-year simulation, this sequence is repeated with initial conditions derived from conditions at the end of the previous year. Parameters such as pnw , over-winter survival factor, and pww, over-winter weight loss factor, are applied to the previous years output.

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Appendix D-l

# Simulation estimates of salmonid predation loss to northern squawfish in a Columbia River reservoir

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## Introduction

Recent studies of three major fish predators in a mainstem Columbia River reservoir demonstrated the importance of predation upon outmigrating juvenile salmonids (Poe & Rieman, ed. 1988). Estimated abundance of the predator species was: northern squawfish, 85000; walleye, 15000; smallmouth bass, 35,000 (Beamesderfer et al. 1988). About 3 million juvenile salmon were lost to predation per year, accounting for about 14% of the annual outmigration of juvenile salmonids. Chinook salmon sub-yearlings suffered the highest mortality: steelhead, chinook yearling, sockeye and coho salmon losses were relatively small. Northern squawfish were responsible for about 80% of the total predation loss (Rieman et al. 1988).

Two models, which include predation components, of the Columbia River system have been developed and are in current use by agencies and researchers in the area. The System Planning Model (SPM) of the Northwest Power Planning Council simulates the complete life cycle of salmon stocks as tributary production, mainstem passage and adult survival and return. Most empahasis is placed upon the freshwater phase of the life history. Predation is not modeled explicitly in the SPM but might be investigated indirectly by adjusting parameters used to compute reservoir survival. Reservoir survival is modeled as a function of flow and reservoir length, thus assuming that smolt mortality is a function of residence time.

Stochastic FISHPASS, developed by Jim Anderson at the University of Washington, is a model that simulates juvenile salmonid passage through Columbia River reservoirs. Passage is simulated as probabilities of movement and mortality of individual fish through the system. Fish travel time, dam mortality and reservoir mortality are the principal sub-model processes considered. Fish travel time is a function of flow velocity, behavior and a random component. Dam mortality depends upon flow streamlines at a dam, fish behavior and vertical distribution of fish in front of the dam. Reservoir mortality is modeled as a function of travel time, predator density and predator activity.

A population dynamics model for northern squawfish developed by Rieman and Beamesderfer (1990) did not include predation processes. This model focused on population growth potential using assumed spawner-recruit relations. A model including predation proportional to predator population size was developed by Beamesderfer et al. (1990). This model assumed that salmonid residence time was inversely related to flow, a predation - temperature relationship peaking at 21.0 deg. C. and was driven by a smoothed daily salmonid passage curve. Results indicated overall mortalities similar to those calculated by Rieman et al.

(1988), but mortalities by salmonid species were not studied. Sensitivity analyses indicated that early season passage and higher passage densities were favorable for increased salmonid survival rates.

The Columbia River Ecosystem Model (CREM) was developed to address specific questions about predation on juvenile salmonids in Columbia River reservoirs. Information collected by USFWS and ODFW since 1982 (Poe & Rieman, 1988) indicated that some species of predators, notably northern squawfish (Ptychocheilus oregonensis), were particularly important to smolt mortality within John Day Reservoir. Predation was also found to vary spatially within the reservoir with the greatest consumption rate of juvenile salmonids occuring near the dams. The consumption rate upon smolts just below McNary Dam was asymptotically related to smolt density (Vigg 1988), with temperature, spawning condition of predators and reservoir flow also affecting the rate. CREM was developed to take into consideration intra-reservoir spatial and temporal variation in predation intensity, species-specific predator-prey interactions, non-linear feeding dynamics, and other within-reservoir components of predation that have not been included in other modeling efforts. The design of CREM allows expansion to a multi-reservoir model, with appropriate estimation of reservoir parameters and extension to a bio-energetic population context for study of long term effects of predator control.

<u>Objectives</u>

1. Develop the Columbia River Ecosystem Model to mathematically describe predatory processes on juvenile salmonids as revealed by research results; to implement a computer simulator for analysis of the model.

2. Based on CREM, parametrized with current research results, test specific hypotheses on the sensitivity of smolt mortality to major driving and system variables:

2.1 Changing the numbers of juvenile salmonids migrating through the system does (does not) affect salmonid mortality rates:

2.2 Changing the mean, or the distribution, of the residence time of juvenile salmonids in the reservoir does (does not) affect their mortality:

2.3 Changing predator densities in different reservoir areas does (does not) affect juvenile salmonid mortality;

2.4 Changing water temperature does (does not) affect juvenile salmonid mortality.

3. Study the predicted variability of juvenile salmonid mortality rates under stochastic uncertainty in the predatory functional response (Vigg 1988).

## Methods

From a strictly ecological perspective, without recourse to mathematics, the Columbia River Ecosystem Model can be described as an abstraction of the processes of juvenile salmonid out-migration through a reservoir and their consumption by predator species. The abstraction approximates movement of salmonids as a progression through a series of contiguous areas of the reservoir, beginning with an area adjacent to the upstream dam. Movement into this first area is driven by a daily record of the numbers of each species passing over the dam, according to records and estimates made by various agencies (Georgi and Sims 1987). The model assumes that salmonids spend an average amount of time in an area and then pass to the next downstream area, leaving at a rate inversely proportional to their density. This simulates departure as the mean of a stochastic Poisson process (Parzen 1962). For this study, the residence times, which are the rate parameters for the Poisson departure process, are taken from the estimates made by Sims and Ossiander (1981). As an alternative to a constant average residence time, the model allows for residence time to be inversely proportional to water flow rate. This alternative is chosen for the tailrace boat restricted zone area in this study. The constant of proportionality is chosen so that residence time is the same as that for a neutrally buoyant particle.

During the time the salmonids are in an area their numbers are reduced by predation. The predation rate depends upon the density of predator fish, the temperature, whether or not the predators are in spawning condition, and the density of salmonid prey. Predator fish density is determined by initial values set according to population studies (Beamesderfer et al. 1988) and is then reduced by a constant assumed instantaneous mortality rate, generally very small or zero. This results in an approximately constant predator density throughout a single year simulation, but different densities in different reservoir areas. Temperature changes the predation rate according to the formulation of Vigg and Burley (1991). Spawning condition of predators is determined by the rate of change of gonad size of predators as measured by Vigg (pers. comm.) and associates. The predation rate is reduced to 10% of maximum, based on reduced stomach contents observed by Vigg.

Dependence upon prey density is determined by a deterministic functional response relation as measured by Vigg (1988). As an alternative, and because of data limitations in the study of Vigg, a stochastic functional response relation may be used. This relation assumes a normal distribution about the deterministic relation for medium and high prey densities, and a uniform distribution for low prey densities. Variance for the two distributions is based on the data shown by Vigg.

Though the simulation is nominally deterministic, any parameter or initial condition of the model may be stochasticized by repeated simulations with parameter choice from any of several standard statistical distributions (normal, uniform, gamma etc.). Results of the simulation are time series of prey and predator densities in each area, cumulative consumed numbers of prey, cumulative prey passage into the reservoir, mortality rate to date and the values of the driving functions (water flow, temperature, gonad condition, prey passage numbers per day); At the end of the simulation the mortality rate, calculated as total numbers of prey consumed divided by total number passing into the reservoir, is the total mortality for the simulated season.

The preceding description in non-mathematical language gives a general idea of the ecological assumptions and methods for **CREM.** To be more precise it is necessary to have a detailed mathematical description which translates the ecological concepts.

Notation and dimensions

In order to facilitate statement and communication of the model we have adopted the following notational conventions.

The principal system variables **(PSV's)** are those variables of the model which are defined by ordinary differential equations whose derivative appears on the left hand side of an algebraic expression, as $Jv_i$ and $Pn_i$ in equations 4, 5 and 6, below. They are symbolized by two letters, the first of which is capitalized, and may be subscripted. The defining expression involves intemediate system variables **(ISV's)**, parameters, forcing functions and, possibly, independent variables (eg, time) and subscripts denoting spatial or other categories.

Intermediate system variables are symbolized by two letters, both lower case, and may be subscripted. **ISV's** are functionally dependent upon other **ISV's**, driving functions or independent variables. Examples are rti, rcji and mti in equations 4, 5 and 6.

Driving functions are symbolized by two letters the first of which is **"F"** and the second of which is lower case. They may be subscripted and are dependent only upon the independent variable, time, as the fishing mortality, Ffi, in equation 6.

Parameters (constants) are variables which do not change value during the course of a simulation. They are symbolized by three or more characters the first of which is "p" and the remainder are chosen to be mnemonic of the PSV or ISV with which they are associated. For example, see prcl in equation 1.

For this system of ordinary differential equations, the only continuous independent variable is time, symbolized as t. Subscripts are a discrete independent variable used to denote spatial location, species or other discrete functional biological groupings (eg juvenile vs. adult). Lower case letters i, j, k and 1 are used exclusively for subscript symbols. The meaning of a subscript suffixed to another variable is determined by the position of the subscript, not the particular symbol used, eg, Ffi and Ffj both denote categories of fishing mortality. In the following model definition, subscripts are omitted except where necessary in the explanation of model mechanisms.

Mathematical functions which are convenient for definition of model mechanisms are symbolized with two lower case letters followed by left and right parentheses enclosing the independent variable(s) and parameters associated with the function. These are defined in the text as they occur. See, for example, at(..) in equation 12 or gg(..) in equation 7. Mathematical operators of summation and differentiation are symbolized by Si[...] and Dt[...], res., where the square brackets help to differentiate the operator notation from function notation. The second character is the indicial variable of the operator. This, for the examples given, is subscript i in the case of summation and independent variable t in the case of differentiation.

The notation described above is used to define the mathematics of the model and is carried over to the computer implementation of the simulator used for analysis of the model, subject only to the syntactical limitations of the programming lanage used. There are a number of symbols required in the computer implementation which do not appear in the mathematical statement of the model itself; symbols are used which do not conflict with the above schema. This approach is intended to simplify the communication of the model to the reader and among research team members and to facilitate the further development of the model. Further, the symbolic notation is chosen to facilitate the typing of mathematical expressions on a single line of a standard computer terminal for easy communication by electronic mail using simple editors and/or word processors without graphic facilities and using a standard ASCII keyboard.

## Columbia River Ecosystem Model. (CREM)

The Columbia River Ecosystem Model is a set of ordinary differential equations for the number density of juvenile salmonid groups, Jv (number/square meter), and predator fish groups, Pn (number/square meter). The groups can be distinished by species, size, age or any other distinct criterion (eg, hatchery vs. wild). Density state variables are specific to each of a series or network of spatial sub-areas covering a contiguous area comprising one or more river impoundments beginning at an upstream dam where passage of salmonid groups has been enumerated (Figure 1). The differential equations resolve, for salmonid prey, three processes: migration into an area, emigration from the area and loss to predation while in the area. These processes can be functionally dependent upon a variety of other system and environmental driving variables. For predator groups, the differential equations resolve mortality due to natural or fishing processes.

Recruitment to the groups is resolved by discrete adjustments to density state variables on an annual basis: growth is represented, where desirable, by an additional state variable for the average weight of each predator group. The differential equation for weight follows the bioenergetic formulation of Bledsoe and Megrey (1989) and resolves metabolic processes of anabolism resulting from food ingestion and catabolic respiration. Neither recruitment nor growth is relevant to the intra-year focus of this study and will not be discussed further except in the context of further research needs.

Movement between contiguous areas is represented by a diffusion-like process characterized by a mean residence time, rt (days), in an area. The loss term for juveniles from an area is

$$Jv / rt$$

which results, for a pulse of incoming juveniles, in an exponential decline in density with loss rate coefficient $rt^{-1}$. The average residence time observed in the solution to the differential equation will then be rt. For groups characterised by a broad distribution of residence times, the model can be parameterised by a series of groups each with a single characteristic residence time and a proportional distribution of densities. Alternatively, the distribution of residence times can be represented by Monte Carlo stochastic simulations or by a series of deterministic simulations with residence times representative of linearized segments of the cumulative distribution of residence times. In this latter case, mortalities or other output statistics can be calculated as weighted sums of the results of the discrete simulations, with weights taken from the distribution of residence times. Residence time, for deterministic simulations, is normally equated to a constant parameter. However, for areas subject to very high flow rates such as the discharge zone of the dam, residence time is assumed to be equal to particle flow time through the area.

Predation processes are represented by a sum of the rates of consumption, rc, over all predator groups for each juvenile group:

$$\Sigma i[\ rci\ ].$$

Each rate of consumption is functionally dependent upon four factors (ISV's), each in turn dependent upon other system variables or driving functions:

1. functional response, fr, is dependent upon juvenile density, Jv;

2. a temperature factor, ct, is dependent upon water temperature, Ft;

3. a spawning condition factor, sp, is dependent upon gonad rate of weight change, Fg;

4. a flow component, fl, is dependent upon flow volume, Fl.

Each of these four functional dependencies is represented by a variable between zero and one, reflecting the degree of attenuation of a maximum consumption rate, prcl. Rate of consumption of the ith juvenile group is the product of these four variables, the maximum consumption rate and the proportion, $jp_i$, which the ith prey species is of total juvenile density, tJv:

$$rc_i = prcl\ fr\ ct\ sp\ fl\ jp_i \qquad 1$$

where

$$jp_i = Jv_i\ /\ tJv \qquad 2$$

and

$$tJv = \Sigma i[\ Jv_i\ ]. \qquad 3$$

Driving variables for this model are time series of juvenile salmonids passing the upstream dam (Fs, numbers / day), flow through the dam (Fl, cubic meters / day), reservoir temperature (Ft, degrees C. as an average for the reservoir) and the gonad rate of weight change for the predator groups (Fg, g/day). Initial conditions are the predator densities by group and reservoir area.

The differential system for the intra-seasonal model (ignoring growth and recruitment of predators) can be summarized in three equations:

$$Dt[\ Jv_1\ ] = Fs - Jv_1/rt_1 - Sj[\ rc_{j1}\ ] \qquad 4$$

where the subscript 1 indicates area 1, the most upstream area of the system and subscript j indicates predator group in area 1.

$$Dt[\ Jv_i\ ] = Jv_{i-1}\ /rt_{i-1} - Jv_i\ /rt_i - Sj[\ rc_{ji}\ ] \qquad 5$$

where subscript i > 1 indicates reservoir area. Equations 3 and 4 indicate that juvenile input to area 1 is determined by the driving function Fs; downstream inflow of **salmonid** juveniles is the outflow from the contiguous'upstream area.

$$Dt[\ Pn_i\ ] = -(\ mt_i + Ff_i\ )\ Pn_i \qquad 6$$

Equation 6 indicates that predator dynamics are determined by the two instantaneous natural (mt) and fishing (Ff) mortalities.

<u>**Ecosystem** simulator</u>

The differential equations comprising the model are implemented as subroutines of a **Fortran** computer program which numerically integrates the equations for a specific set of parameter values, driving functions and alternative functional relations among the four which determine consumption rate as described above. The version of the simulator (1.3) used for this study incorporates options for repeated simulations with modification of parameter values at each execution and addition of stochastic components to the sigmoid functional response **curve.**

Specific functional forms which relate the rate of consumption to other system variables are as follows in version 1.3. Parameter values used are given in appendix 1.

Temperature modulates consumption rate by a smoothly peaked function with maximum at 21 deg. C.; figure 2 shows the functional relation and the observed data upon which the function is based. The equation used in the simulator is:

$$ct = gg(Ft,\ 0.,\ prc4,\ prc5,\ prc6) \qquad 7$$

where gg(..) is a four parameter "generalized **gamma"** (Vigg and Burley 1991) function defined by

$$gg(x,a,b,c,d) = z^c \exp\{\ (c/d)\ (1 - z^d)\ \} \qquad 8$$

and

$$z = (x - a)/(b - a). \qquad 9$$

The functional response curve is a sigmoid form shown in figure 3, with the observed data upon which it is based. The equation used is:

$$fr = sg(tJv, prc2, prc3) \tag{10}$$

where sg(..) is a two parameter sigmoid function defined by

$$sg(x,a,b) = 1./ (1. + a \exp\{-b\ x)). \tag{11}$$

Attenuation of consumption during spawning is effected through a driving function, Fg, which is the average rate of change of gonad size in female predators. The spawning effect ISV, sp, is calculated as a function of Fg:

$$sp = pspl + (1.0 - psp1)\ at(Fg, psp2, psp3). \tag{12}$$

In equation 12, at(...) is a two parameter doubly asymptoting function calculated from the arc tangent trigonometric relation by linearly transforming both dependent and independent variables:

$$at(x, a, b) = pi"\ \tan^{-1}\{\ c\ (x - a)) \tag{13}$$

where

$$c = \tan(.4\ pi) / b \tag{14}$$

and pi = 3.14159... Parameter values are chosen so that sp will have a value of about 0.20 whenever the gonads are losing weight, i.e. Fg < 0. The value of sp will rise abruptly toward 1.0 as Fg becomes positive.

Attenuation of consumption during times of extremely high flow, such as occurs in the tail race close to the spill ways, is effected by calculation of fl as

$$fl = sw( Pn, 0., pvt - Fl / pa) \tag{15}$$

where pvt is a flow velocity threshold, Fl is river flow rate in volume units per day, pa is the surface area of the relevant area and sw(...) is a threshold switching function defined as

$$sw(x, y, a) = \begin{cases} x & \text{if } a > 0.0 \\ y & \text{if } a < 0.0. \end{cases} \tag{16}$$

This formulation will have the effect of setting the effective predator density to zero whenever the-velocity threshold is exceeded in a river area by current velocity.

## Simulator configuration

The CREM simulation program was configured with the parameter values listed in appendix 1 to describe a two area subdivision of John Day Reservoir downstream from McNary Dam on the Columbia River. Area 1 of the simulation was configured for the one-half kilometer (approx.) section (460,000 $m^2$) immediately below McNary Dam, called the boat restricted zone (BRZ). Area 2 was the remainder of the reservoir (210 million $m^2$) 95 km (approx.) in length. Water temperature, daily dam discharge and juvenile salmonid daily migration indices used to drive the simulator were from 1985 records. Only predation by large (greater than 400 mm fork length) northern squawfish was simulated: predator numbers assumed in the two reservoir areas were 2,800 in area.1 and 82,000 in area 2 (Beamesderfer and Rieman 1988). Predator numbers were assumed to be attenuated by an instantaneous mortality rate of 5% $yr^{-1}$. Five juvenile salmonid types were simulated: sub-yearling chinook, yearling chinook, steelhead, coho and sockeye. The simulated time period was from Julian day 91 to 241. The differential equations were integrated with an Euler (first order) method. A time step smaller than 0.01 days was found to result in no further change in simulation results in the third significant digit for any model variable: 0.01 days was accordingly chosen as the time step for all simulations.

The simulator reported time series of juvenile salmonids by area and type, predator numbers by area, cumulative consumption by salmonid type, predator type and area and cumulative salmonid fractional mortality by type and area.

# Results

## Simulation of 1985 mortality

Figure 4 shows the time series of reservoir temperature, flow and predator gonad index with daily passage numbers and cumulative mortality for two species of juvenile salmonids. Table 1 gives total mortality in areas 1 (BRZ) and 2 (reservoir) for all five juvenile salmonid types. For purposes of 'comparison with the exercises reported below, these results will be referenced as the standard simulation.

Although direct empirical measures of total salmonid mortality are not practical, the simulated mortality projected by CREM can be compared in aggregate with the estimates reported by Rieman et al. (1988). This report made mortality estimates based on predator daily consumption measurements and used simple algebraic methods to scale daily consumption rates up to seasonal values and measured predator population levels. The methods of Rieman et al. did not consider effects of salmonid density, temperature, flow rate, juvenile residence time or predator spawning but they did consider empirical monthly variation in consumption rate, the same areas configured into CREM and reported the inter-annual variance in consumption rate per predator and total salmonids lost. Due to the different methods of aggregating mortality estimates in this study and in Rieman et al., only the total season mortality of salmonids excluding steelhead can be compared. This value was 0.11 for the Rieman et al. study (calculated from values reported in table 1, appendix table 5 and the reported fraction of predation due to northern sguawfish, 0.78). The comparative value from the CREM simulation results was 0.44.

Predator Removal Simulations

Several simulations were conducted to examine the effects of pool-wide removals of northern sguawfish within John Day Reservoir. Predator removal simulations were compared with the standard simulation that used the northern sguawfish population estimates of 82,000 adult sguawfish in the pool. Figure 5 shows the time series of mortality for sub-yearling chinook with 50% and 90% of sguawfish removed from the reservoir. When 50% of the northern squawfish were removed (41,000) from the pool, mortality rate of sub-yearling chinook declined only 36-43% during the period of peak smolt passage (Julian day 160-210). The number of sub-yearling chinook lost to predation in the pool by the end of the summer (Julian day 241) was 5.4 million with 50% predator removal compared to 7.5 million for the standard simulation, a 28% reduction. When 90% of the northern squawfish were removed from the pool, leaving only 8,200 predators, mortality rate declined roughly proportionally (about 90%) to the predator removal (Figure 5). The number of smolts lost in the pool by day 241 was 1.5 million, an 80% reduction.

Temperature Chanse Simulations

Temperature affects the rate of consumption by northern squawfish of juvenile salmonids (Vigg and Burley 1991). Mean daily water temperatures during summer months may change by several degrees from year to year and the impoundment of the Columbia River by large dams caused summer water temperatures to increase by as much as 1.5 deg. C over pre-impoundment days (Novotny and Clark, unpublished report). Two simulations were conducted to investigate extreme warm- versus cold-water years. Normally, water temperatures do not increase much until mid-May so May 15 was chosen as the date when temperatures could be divergent between different years. Between May 15 and September 1, daily input temperatures were raised or lowered by 3 degrees C. Figure 6 summarizes the results of these analyses, showing reservoir mortality time series for sub-yearling chinook.

Decreasing daily water temperature by 3 deg. C caused June through August mortality to decrease 20-40% during the period of high smolt passage, compared to the standard simulation. During this period, mortality increased from 0.10 to 0.59 with the lowered temperatures but increased from 0.17 to 0.65 in the standard simulation. Total number of sub-yearling chinook lost to predation by the end of the summer in the reservoir and BRZ during the lowered temperature simulation was 6.9 million, compared to 7.5 million during the standard simulation.

Increasing the water temperature by 3 deg. C for each day following May 15 caused a more complicated pattern of mortality change. Until mid-July (Julian day 191), the rate of mortality was slightly higher in the warmer-water simulation compared to the standard simulation, but by late July (Julian day 201) mortality rate had dropped below the mortality rate of the standard simulation and continued to be relatively low throughout the remainder of the summer. Mortality for the warm-water simulation was, in fact, lower than mortality in the cold-water simulation from about day 201 until the end of the simulation. With warm water conditions, the relatively lower rate of mortality during the latter portion of the sub-yearling chinook passage caused the total number of smolts consumed (5.4 million) to be significantly less than in the standard simulation (7.5 million) or the cool-water simulation (6.9 million).

Residence Time simulations

Average residence time of juvenile salmonids within John Day Reservoir has been estimated by Sims and Ossiander (1981) to be 21 days for sub-yearling chinook and 4 days for other salmonid species. We constructed a frequency distribution of individual residence times for a relatively large number of marked and recaptured fish from data in Miller and Sims (1984); figure 7 shows the results. These data suggest that reservoir residence times for sub-yearling chinook may be as short as five days or exceed 100 days. The distribution of these data is highly skewed with a mean of 31 days and a median of 49 days. Because of the skewness and variability in residence time data for sub-yearling chinook, several CREM simulations were performed to investigate the effects of different residence times in John Day Reservoir and to obtain an estimate of reservoir mortality based on accurate representation of the residence times found by Miller and Sims.

The cumulative distribution function (cdf, figure 7) of sub-yearling chinook residence times was divided by eye into five approximately linear intervals. This procedure was able to match the cdf with an error of less than 1% of its maximum of 641 tagged and recovered juvenile salmonids. The midpoints (and frequencies relative to 1.0) of the linear segments of the cdf are given in the first two columns of table 2; these correspond to widths and heights of blocks in a smoothed histogram approximation of the highly erratic frequency distribution shown in figure 7. Five simulations were performed with mean residence times corresponding to the residence times in table 2; sub-yearling chinook predation losses and mortalities are-shown in figure 8 and table 2.

As expected, short residence times (eg., 7 days) within the reservoir resulted in relatively low rates of mortality while extended residence times caused mortality to be as high as 0.9 by the end of the summer. Rapid passage of smolts through-the reservoir resulted in a sub-yearling chinook mortality of 0.37 by day 241 whereas mortality was 0.79 or higher if they remained in the reservoir for 39 or more days.
The weighted mean mortality for the five simulations with different residence times was 0.61. Mortality in the standard simulation using a 21 day reservoir residence time was 0.65.

## Density Deoendent Consumption Effect

Because of the non-linearity in the functional response curve, increased density of juveniles beyond the inflection point should result in decreased mortality rates due to a swamping effect on the predtors. To test this effect a series of simulations were conducted with artificially increased passage rates of sub-yearly chinook. Table.3 shows the results of these simulations.

## Uncertainty in the Functional Response Curve

The data used to estimate the functional response relationship (figure 3) has a data distribution which is highly skewed to lower values of salmonid density. In order to test the sensitivity of CREM predictions to the consequent uncertainty in the functional response, a stochastic version of the CREM simulator was implemented. This version was designed to choose values for the functional response ISV (fr) based on the juvenile density and/or the deterministic value of fr according to a specified distribution function. This was accomplished through use of a pseudo-random uniformly distributed random number generator algebraically transformed to give the desired distribution. A choice of values for fr is made in the CREM simulator for each interval over which a solution to the differential equations is approximated.

For salmonid densities below 0.0035 $/m^2$, figure 3 shows no coherent form. Analysis of consumption rate data for this range of salmonid densities indicated that an approximately uniform distribution was appropriate. Above this range, consumption rates were distributed approximately normal-ly about the sigmoidal curve with a 10% coefficient of variation. These mechanisms were incorporated into the stochastic simulator and two simulations with different initial seed values- for the pseudo-random number generator were performed. Figure 9 shows a sub-sample of the values of fr which were utilized in one of these simulations. Figure 10 shows the time series of mortality for sub-yearling chinook generated by the two stochastic simulations, in comparison with the time series from the standard simulation. No more than two stochastic simulations were performed because of the similarity of the two.

## Discussion

The total season mortality for non-steelhead salmonids (0.44) was much larger than that calculated by Rieman et al. (1988). This was because the latter study did not take into account the extended residence time of sub-yearling chinook relative to other salmonids. **CREM** makes the assumption that mortality occurs in proportion to length of time exposed to predators. If the results of Rieman et al. are pro-rated in order to calculate predation rates for other than sub-yearling chinook, the mortality values predicted by **CREM**, 0.089, are comparable.

Mortality rates in the reservoir are predicted to be much higher than those in the BRZ, in contrast to the reported higher consumption rate of juveniles by northern **squawfish** in the BRZ (Rieman et al. 1989). The higher mortality rates in the reservoir are not an unreasonable expectation when the relative residence times of juveniles in the BRZ relative to the reservoir are taken into consideration. Predators are more dense in the BRZ (16X), however the much greater size of the reservoir (456X) together with the much longer residence time (4 days vs. 15 minutes typical for early spring flow rates) much more than compensates for the increased density. Studies subsequent to this analysis have indicated that reservoir **salmonid** consumption rates by individual predators are lower than in the BRZ because the predators have a more varied diet in the main **reservoir** (Vigg, pers. **comm.).** This study assumed the same consumption to **salmonid** density relationship in the reservoir and the BRZ. Consideration of the diet quality differences in the two areas should lower the reservoir mortality estimates, but the profound effect of extended residence time will still be important. The diet quality differences are being considered in future research using **CREM.**

The reason for the non-proportional survival of **smolts** following simulated predator removal is the nonlinear response of consumption rate versus prey density. Fewer predators results in higher prey densities but the rate of change in consumption slows at very high prey densities when the functional response curve is operating near its asymptote.

The reason for the reduced **mortality** under warm water conditions was the reduced rate of northern squawfish feeding when temperatures are greater than 21.5 deg. C. according to the curve shown in figure 2. As the water temperature increases during the season, increased mortality will result until the temperature reaches the maximum of figure 2 at 21.5 degrees. Any subsequent temperature increase will result in decreased feeding and decreased mortality rates. The three degree increase simulated corresponded to extremely warm reservoir temperatures late in the season.

The residence time simulations for sub-yearling chinook showed very high reservoir mortality for these native (non-hatchery) salmonids. Though substantial mortality to hatchery released juveniles is due to predation, the naturally reared juveniles are subject to much greater predation pressure. This is due to the much greater residence time in the pool of the sub-yearling chinook, as revealed by re-analysis of the data of Sims and Ossiander (1981, see figure 7). The use of a single residence time comparable to the mean of the highly skewed, temporally distributed residence time did result in mortality predictions which were very similar (0.61 vs. 0.65), indicating that the Poisson process assumptions of CREM will yield useful results even when migration patterns are compound Poisson processes.

The objective of the exercise in which juvenile daily passage numbers were increased several fold was to determine to possible value of concentrating juveniles to take advantage of the asymptotic nature of the functional response curve to reduce mortality. Table 3 show that mortality rates can be decreased but 42% mortality is still much too large to be acceptable. The practicality of this approach would depend upon a method for "focusing" passage into a narrow time window: this is currently beyond technical capability.

One of the most salient criticisms of this and other Columbia River fish passage models might be the amount and type of data used to design the mechanisms involved. The distribution and amount of data shown in figure 3 is far from the most desirable, however the shape is in full agreement with existing ecological theory. The value of the exercise to stochasticize the functional relation is that a great deal more data points would not yield different results in terms' of mortality rates, so long as that data assumed the same basic form of the existing curve. While this does not indicate that no more consumption rate data is needed, it does say that our research should be focused on methods which might contradict the past research, rather than simple repetitions of the previous methods,

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Beamesderfer, R.C., B.E. Rieman, L.J. Bledsoe and S. Vigg. 1990. Management implications of a model of predation by a resdent fish on juvenile salmonids mirating through a Columbia River reservoir. N. Amer. J. Fish. Mgmt. 10(3):290-304.

Georgi, A.E. and C.W. Sims. 1987. Estimating the daily passage of juvenile salmonids at McNary Dam on the Columbia River. N. Amer. J. Fish. Mgmt. 7:215-222.

Miller, D.R. and C.W. Sims. 1984. Effects of flow on the migratory behavior and survival of juvenile fall and summer chinook salmon in the John Day Reservoir. Report (Contract DE-AI79-83BP39645) to Bonneville Power Administration, Portland Oregon.

Parzen, Emanuel. 1962. Stochastic processes. Holden-Day, Inc., San Francisco. 324 pp.

Poe, T.P., and B.E. Rieman, editors. 1988. Predation by resident fish on juvenile salmonids in John Day reservoir, 1983-1986. Final Report (contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) to Bonneville Power Administration, Portland, Oregon.

Rieman, B.E., R.C. Beamesderfer, S. Vigg and T.P.Poe. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia reservoir: Part IV. Estimation of total loss and mortality of juvenile salmonids to northern sguawfish, walleye and smallmouth bass. Pages 249-273 in Poe and Rieman, eds. (1988) .

Rieman, B.E. and R.C Beamesderfer. 1990. Dynamics of a northern sguawfish population and the potential to reduce predation on juvenile salmonids in a Columbia River reservoir. N. Amer. J. Fish. Mgmt. 10(2):228-241.

Sims, C.W. and F.J. Ossiander. 1981. Migrations of juvenile chinook salmon and steelhead trout in the Snake River from 1973 to 1979. Report (Contract DACW57-83-F-0314) to U.S. Army Corps of Engineers, Portland Oregon.

Vigg, S. 1988. Functional response of northern squawfish predation to salmonid prey density in McNary tailrace, Columbia River. Pages 174-207 in: T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day reservoir, 1983-1986. Final Report (contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) to Bonneville Power Administration, Portland, Oregon.

Vigg, S., and C.C. Burley. 1991. Temperature dependent maximum daily consumption of juvenile salmonids by northern squawfish (Ptychocheilus oregonensis) from the Columbia River. Can. J. Fish. Aquat. Sci. 48 (In press),

Table 1. Total predation mortalities and numbers lost (parentheses, 000's) by area and salmonid type for John Day Reservoir in 1985, based on simulation with the Columbia River Ecosystem Model.

| Reservoir Area | Juvenile Salmonid Type: Sub-yearling Chinook | Yearling Chinook | Steelhead | Coho | Sockeye |
|---|---|---|---|---|---|
| BRZ | 0.021 (240) | 0.0029 (15) | 0.0035 (0) | 0.0039 (0) | 0.0037 (6) |
| Reservoir | 0.65 (7400) | 0.081 (444) | 0.099 (153) | 0.12 (15) | 0.096 (181) |

Table 2. Mean residence times and associated frequencies for sub-yearling chinook from data of Miller and Sims (1984); predation loss and mortalities associated with each mean residence time.

| Residence Time (d) | Frequency | Total Sub-yearling chinook Lost by day 241 ($X\ 10^6$) | Total mortality |
|---|---|---|---|
| 7 | 0.30 | 3.9 | 0.35 |
| 18 | 0.28 | 7.1 | 0.62 |
| 39 | 0.27 | 8.7 | 0.76 |
| 88 | 0.14 | 9.7 | 0.85 |
| 134 | 0.01 | 10. | 0.88 |
| | | Weighted average | 0.61 |

Table 3. Predation loss and mortalities predicted by CREM for increased levels of daily passage of sub-yearling chinook salmon.

| Increase Factor | Predation Loss ($X10^6$) | Mortality (reservoir) |
|---|---|---|
| 2x | 11. | 0.60 |
| 3x | 13. | 0.49 |
| 4x | 14. | 0.42 |

## Figure captions

Figure 1. Diagram of processes and variables in the Columbia River ecosystem model (CREM).

Figure 2. Generalized gamma function fit to data describing experimentally determined relation of maximum consumption rate to water temperature. Adapted from Vigg and Burley 1991.

Figure 3. Functional response model of salmonid consumption by northern squawfish versus salmonid prey density in the tailrace of McNary Dam, Columbia River, 1983-1986 (Vigg 1988).

Figure 4. Time series of model output for 1985 simulation of predation mortality on John Day Reservoir. a. Model driving functions: dam flow (Fl), reservoir temperature (Ft), gonad rate of change of weight (Fg). Daily passage rate and cumulative mortality for (b) coho and (c) sub-yearling chinook juveniles.

Figure 5. Simulated effect of different levels of predator removal from reservoir areas on mortality of sub-yearling chinook.

Figure 6. Simulated effect of reservoir temperature change on sub-yearling chinook mortality.

Figure 7. Frequency distribution and cumulative frequency distribution of residence times in John Day reservoir for sub-yearling chinook salmon. Data are from Miller and Sims (1984). Straight line segments were fit by eye in order to simulate the effect on mortality of the skewed distribution of residence times.

Figure 8. Effect of residence time on cumulative mortality of sub-yearling chinook salmon.

Figure 9. Sub-sample of values of the functional response ISV, fr, used in stochastic simulations to test the sensitivity of the functional response relation. Open boxes are the. values which would have been used in a deterministic simulation: pluses (+) are the actual values used. a. Two out of each 100 values used in area 1 (BRZ). b. Values used between days 150 and 180 in area 2 (reservoir).

Figure 10. Time series of mortality for sub-yearling chinook in area 2 (reservoir) simulated using a stochastic functional response relation. Open boxes are results of the standard simulation, pluses (+) and diamonds are from the two stochastic simulations.

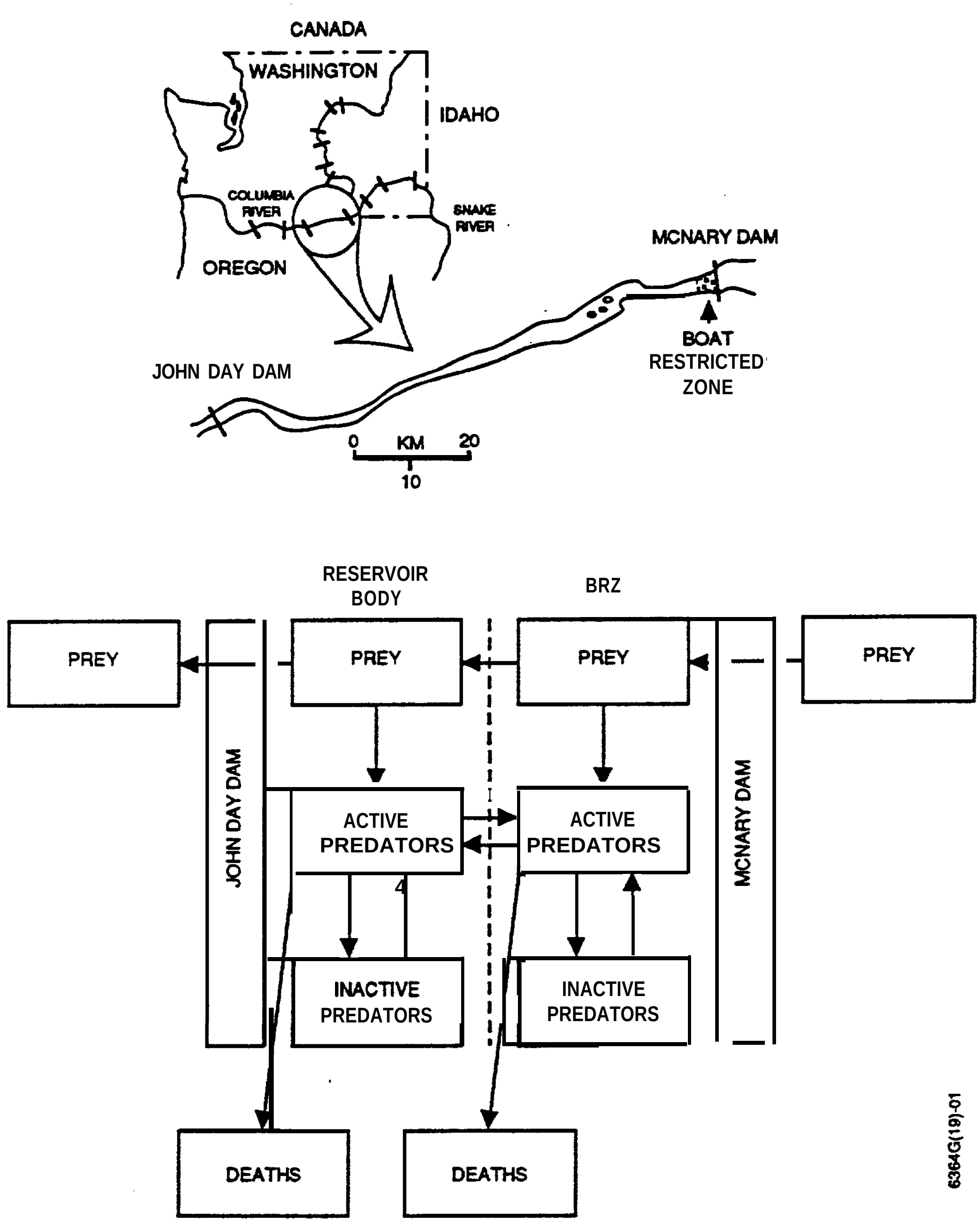

CANADA
WASHINGTON
IDAHO
COLUMBIA RIVER
SNAKE RIVER
OREGON
MCNARY DAM
BOAT RESTRICTED ZONE
JOHN DAY DAM
0 KM 20
10
RESERVOIR BODY
BRZ
PREY
PREY
PREY
PREY
JOHN DAY DAM
ACTIVE PREDATORS
ACTIVE PREDATORS
MCNARY DAM
INACTIVE PREDATORS
INACTIVE PREDATORS
DEATHS
DEATHS
6364G(19)-01

Figure 1

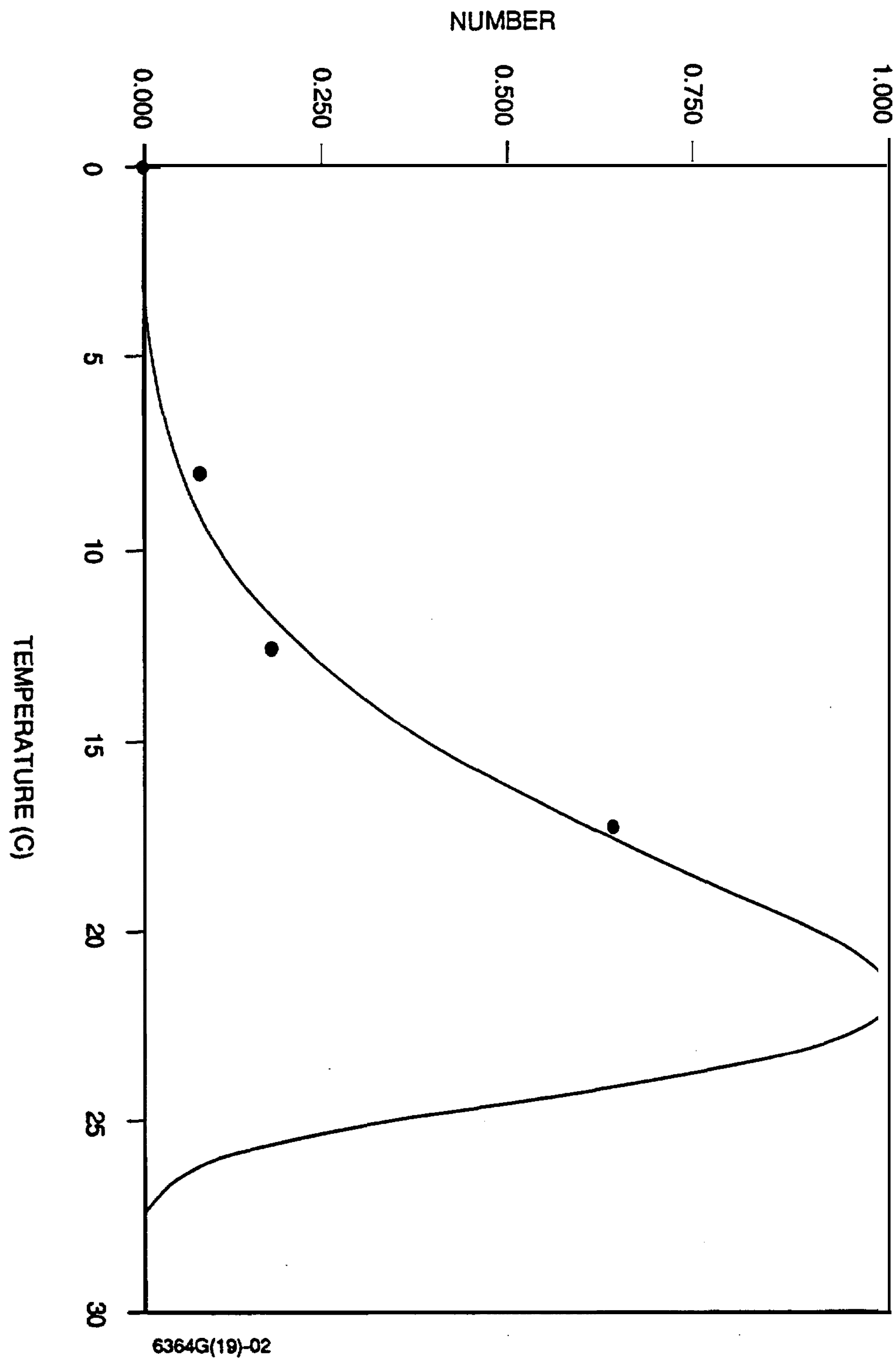
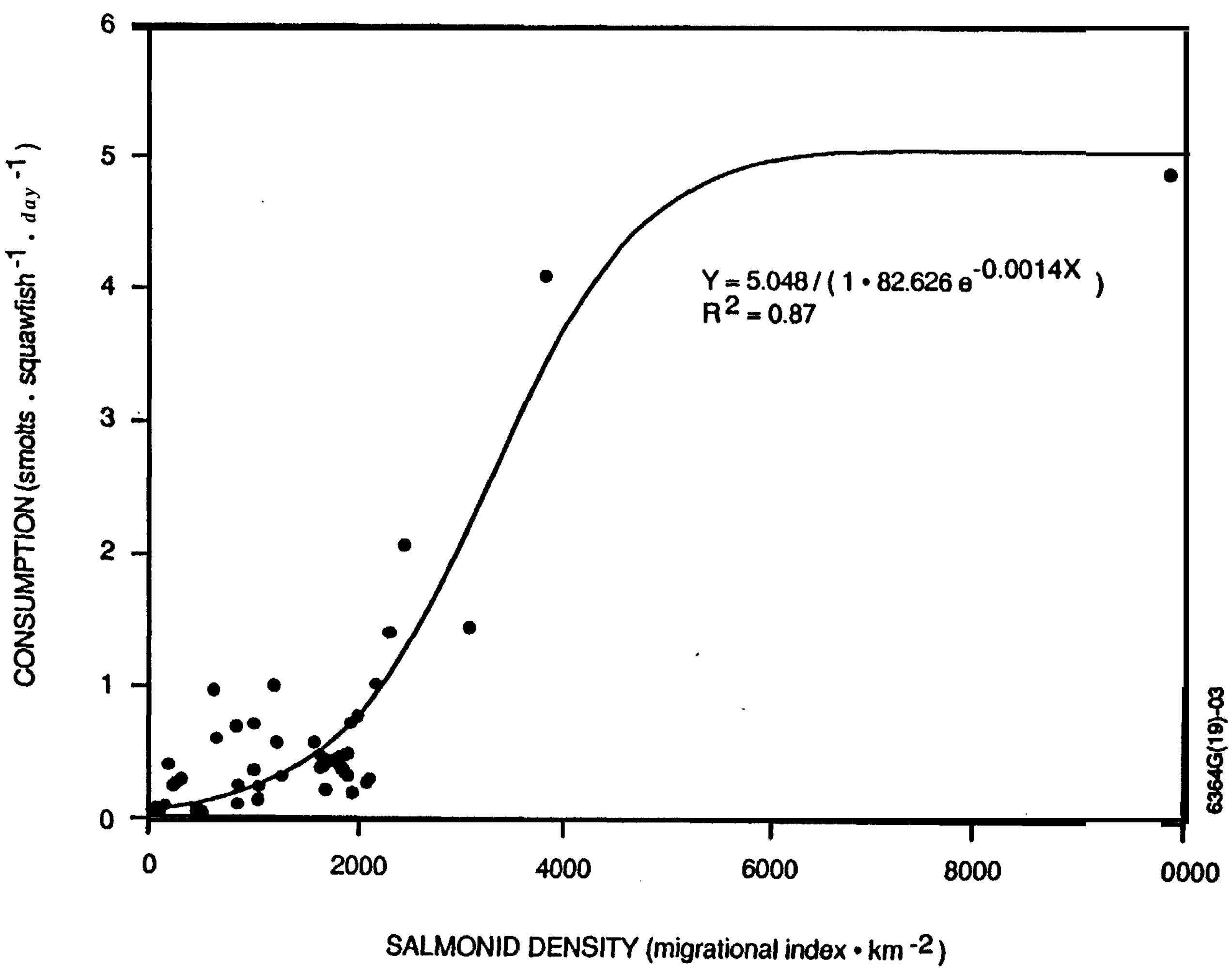

NUMBER
0.000
0.250
0.500
0.750
1.000
0
5
10
15
20
25
30
TEMPERATURE (C)
6364G(19)-02

Figure 2.



CONSUMPTION (smolts . squawfish -1 . day -1 )
0
1
2
3
4
5
6
0
2000
4000
6000
8000
0000
Y = 5.048 / ( 1 • 82.626 e -0.0014X )
R 2 = 0.87
SALMONID DENSITY (migrational index • km -2 )
6364G(19)-03


Figure 3.

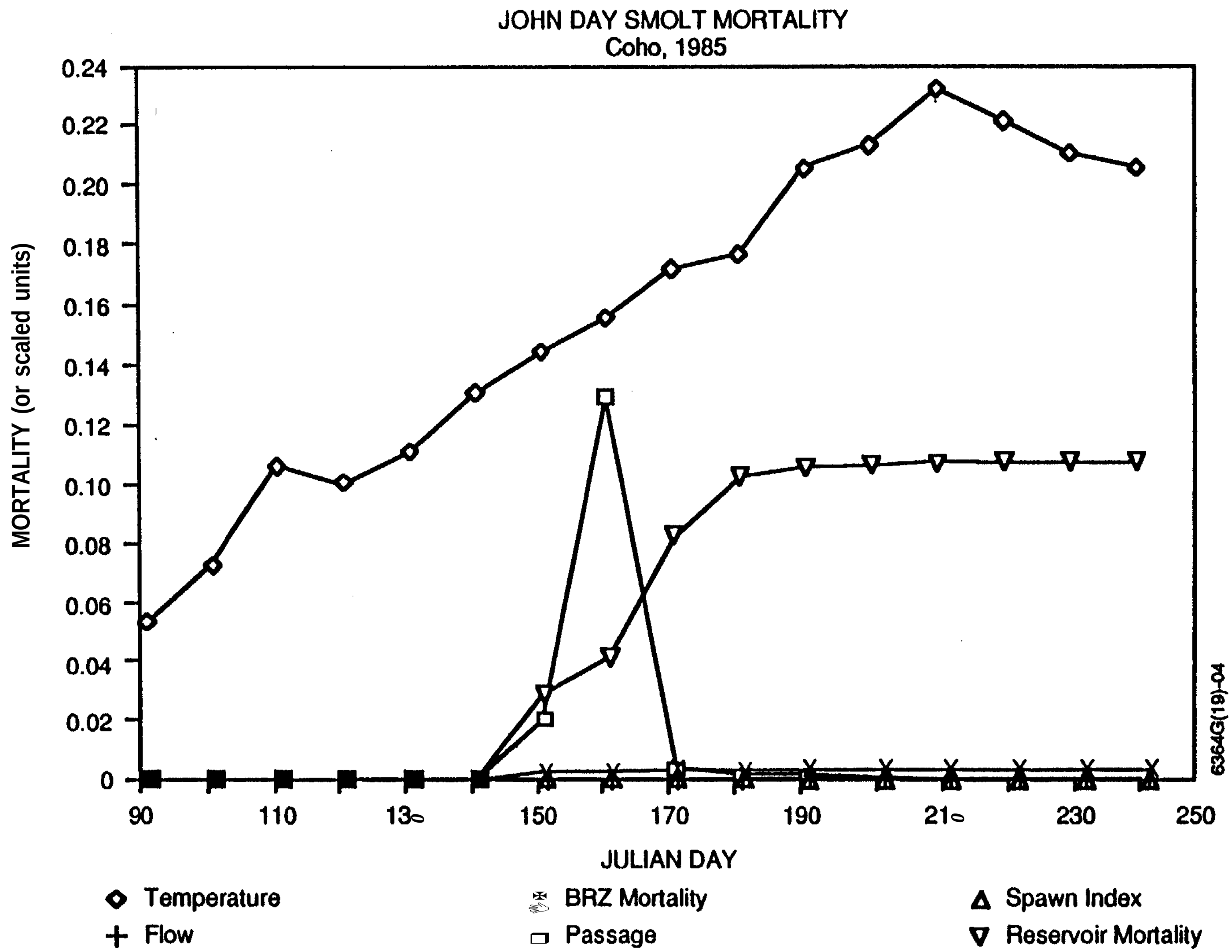

JOHN DAY SMOLT MORTALITY
Coho, 1985
MORTALITY (or scaled units)
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
90
110
130
150
170
190
210
230
250
JULIAN DAY
6364G(19)-04
Temperature
Flow
BRZ Mortality
Passage
Spawn Index
Reservoir Mortality

Figure 4a.

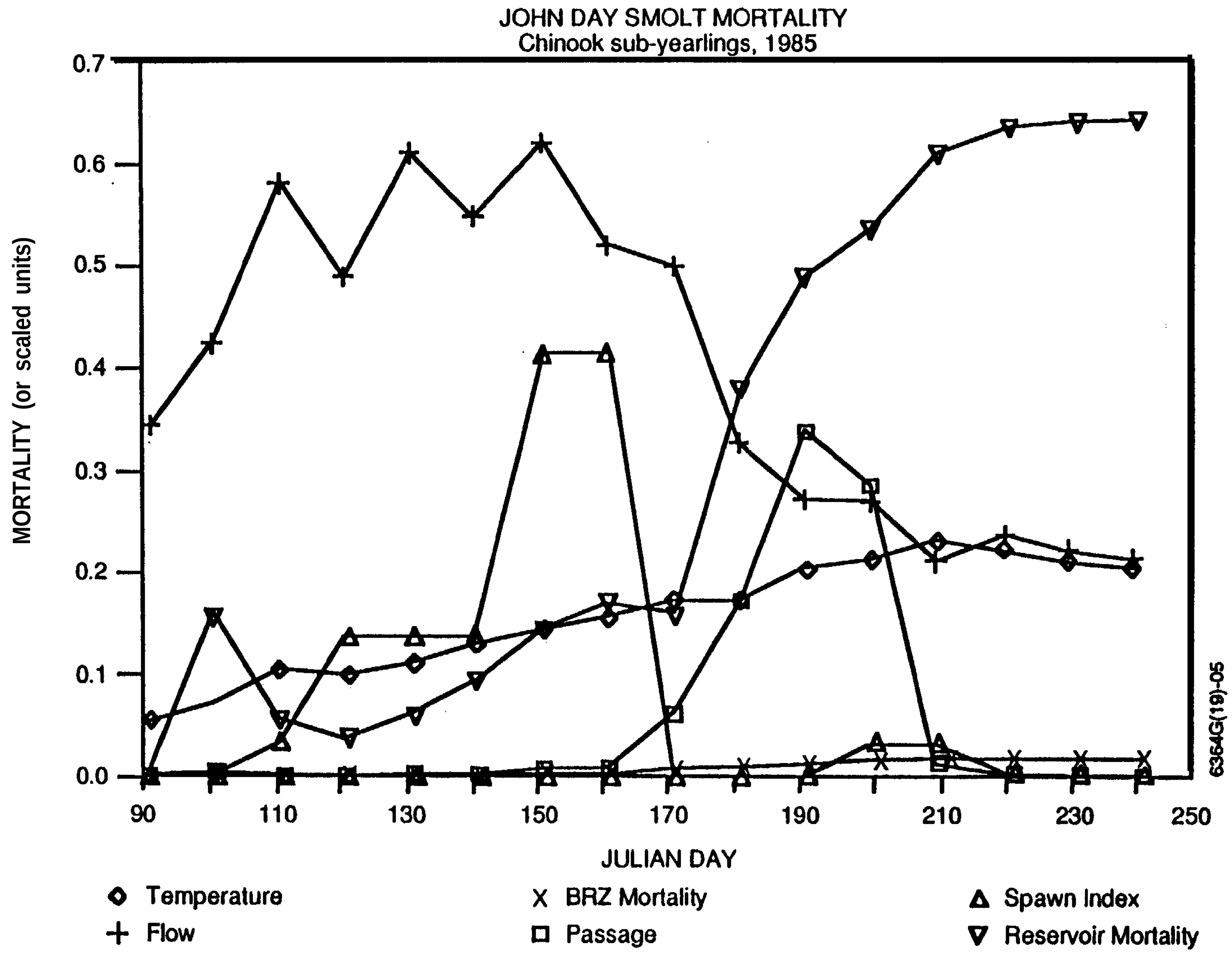

JOHN DAY SMOLT MORTALITY
Chinook sub-yearlings, 1985
MORTALITY (or scaled units)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
90
110
130
150
170
190
210
230
250
JULIAN DAY
6364G(19)-05
Temperature
Flow
BRZ Mortality
Passage
Spawn Index
Reservoir Mortality

Figure 4b.

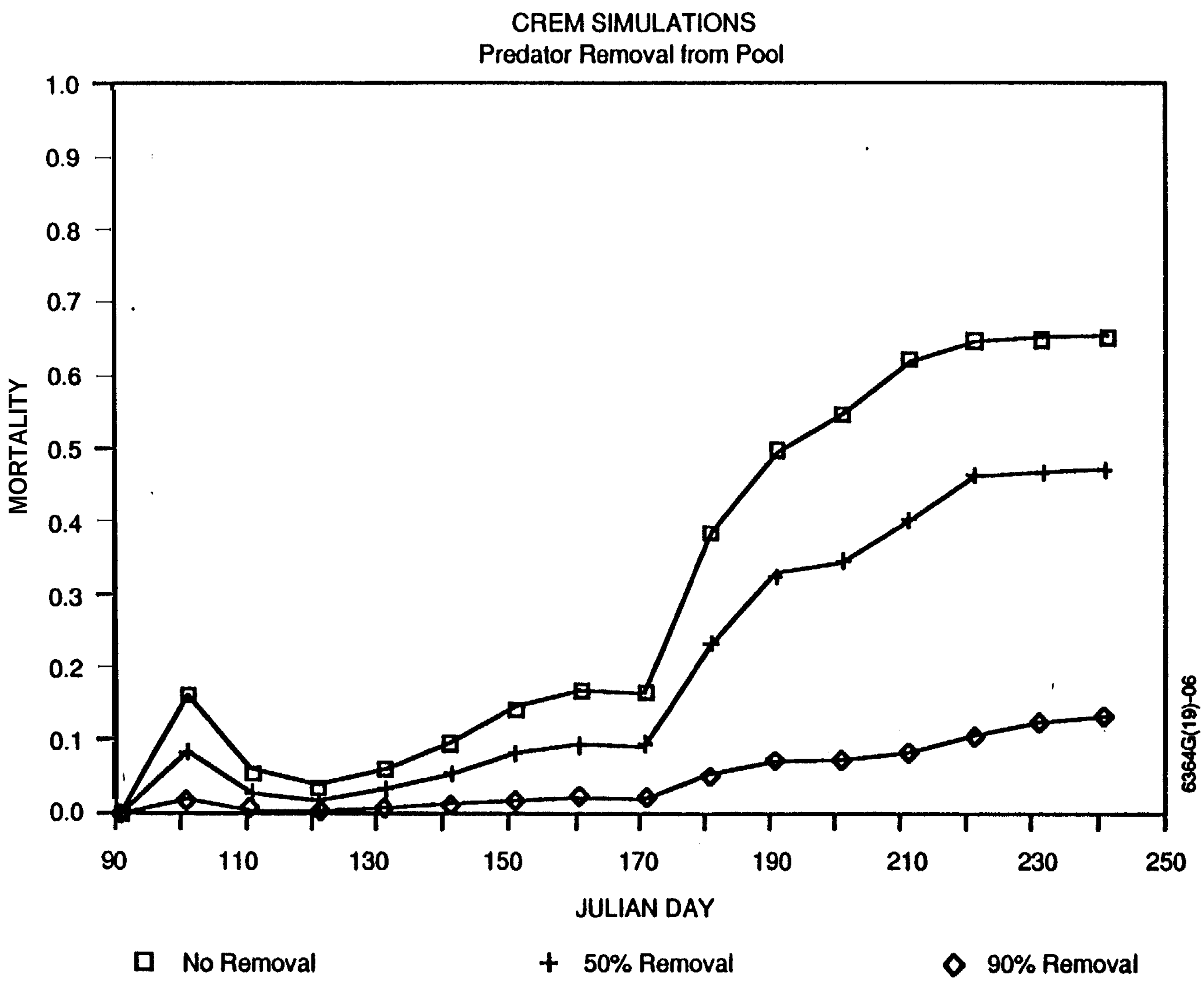

CREM SIMULATIONS
Predator Removal from Pool
MORTALITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
90
110
130
150
170
190
210
230
250
JULIAN DAY
6364G(19)-06
No Removal
50% Removal
90% Removal

Figure 5.

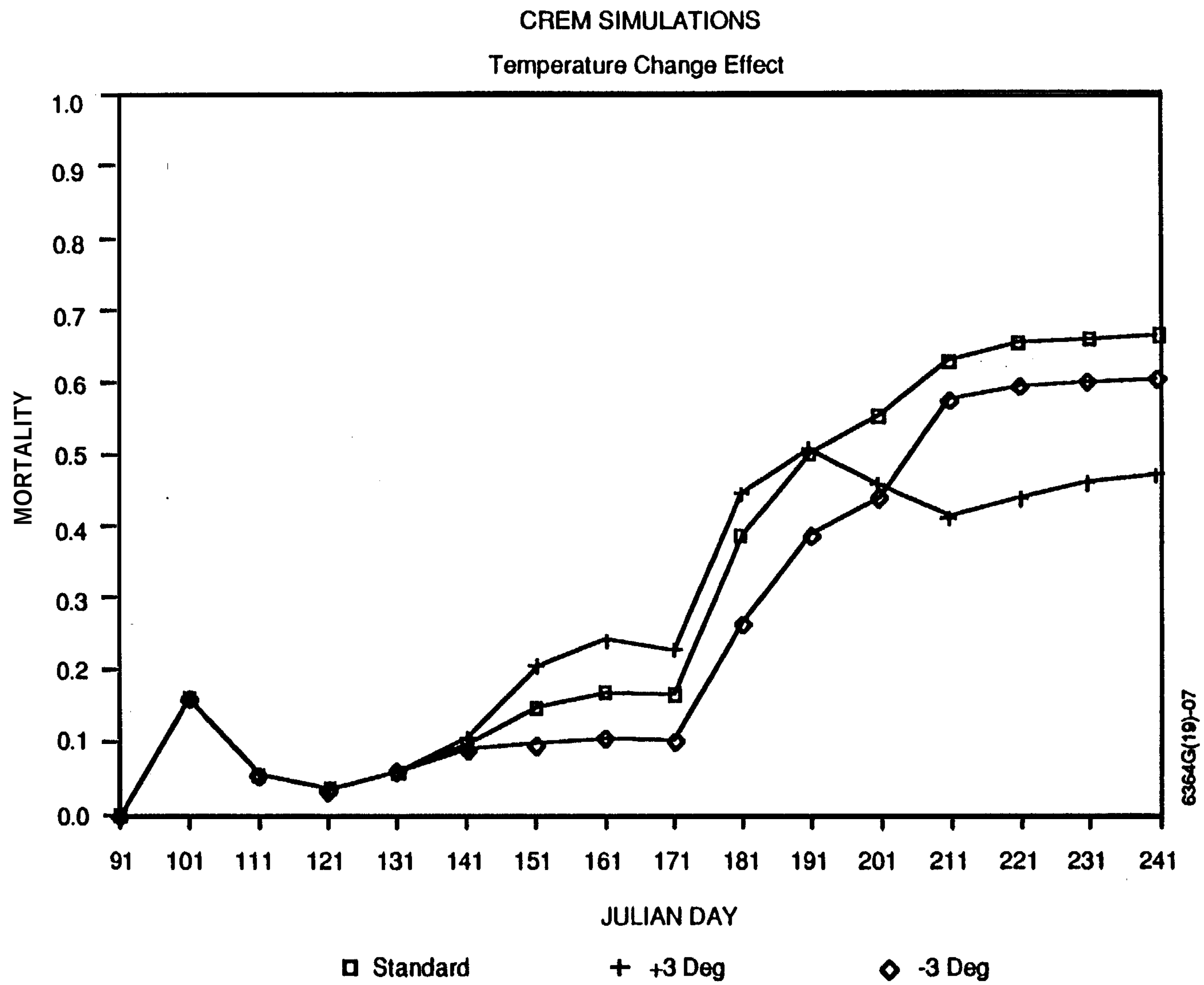
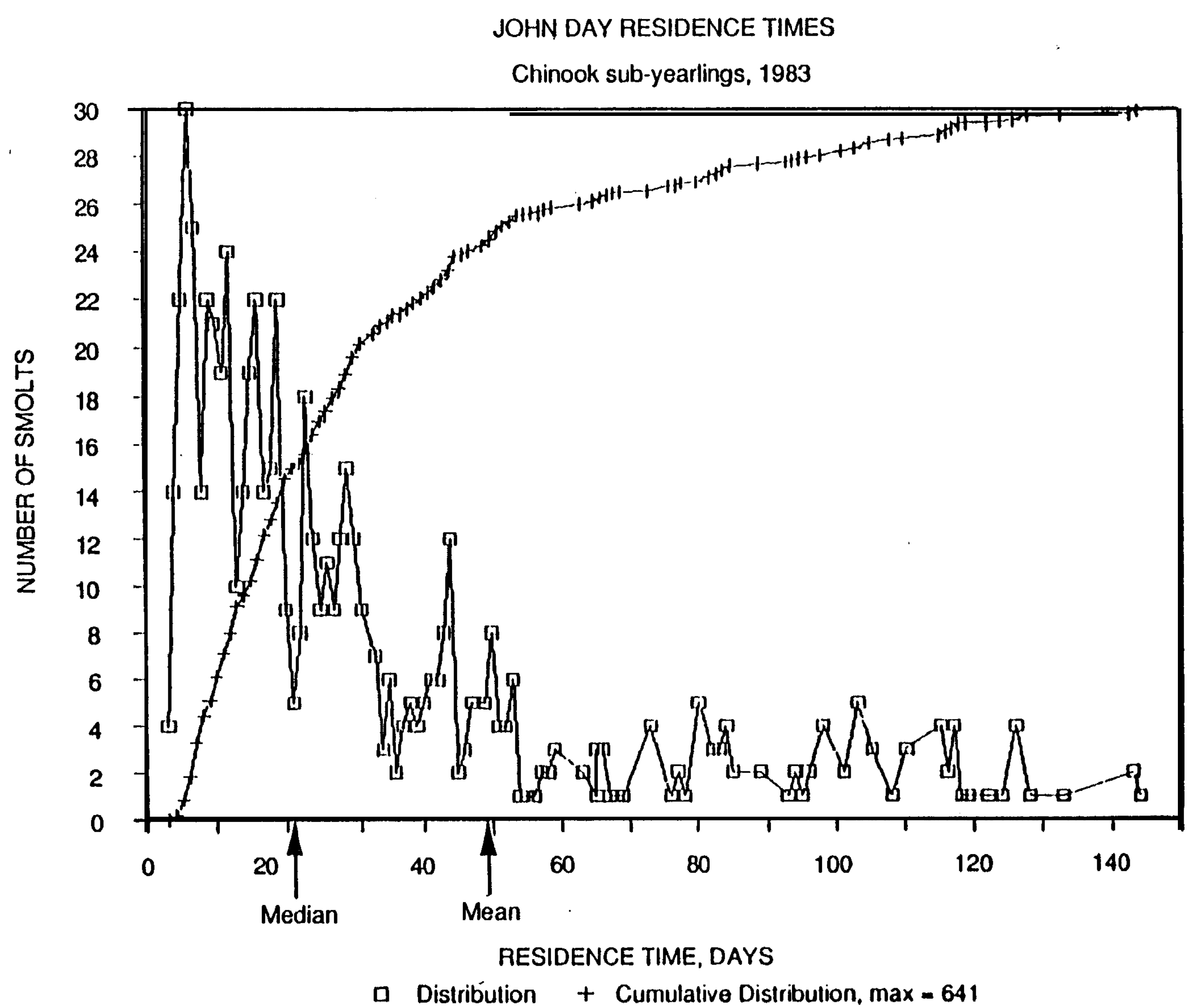

CREM SIMULATIONS
Temperature Change Effect
MORTALITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
91
101
111
121
131
141
151
161
171
181
191
201
211
221
231
241
JULIAN DAY
Standard
+3 Deg
-3 Deg
6364G(19)-07

Figure 6.



JOHN DAY RESIDENCE TIMES
Chinook sub-yearlings, 1983
NUMBER OF SMOLTS
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0
20
40
60
80
100
120
140
Median
Mean
RESIDENCE TIME, DAYS
Distribution
+ Cumulative Distribution, max = 641


Figure 7.

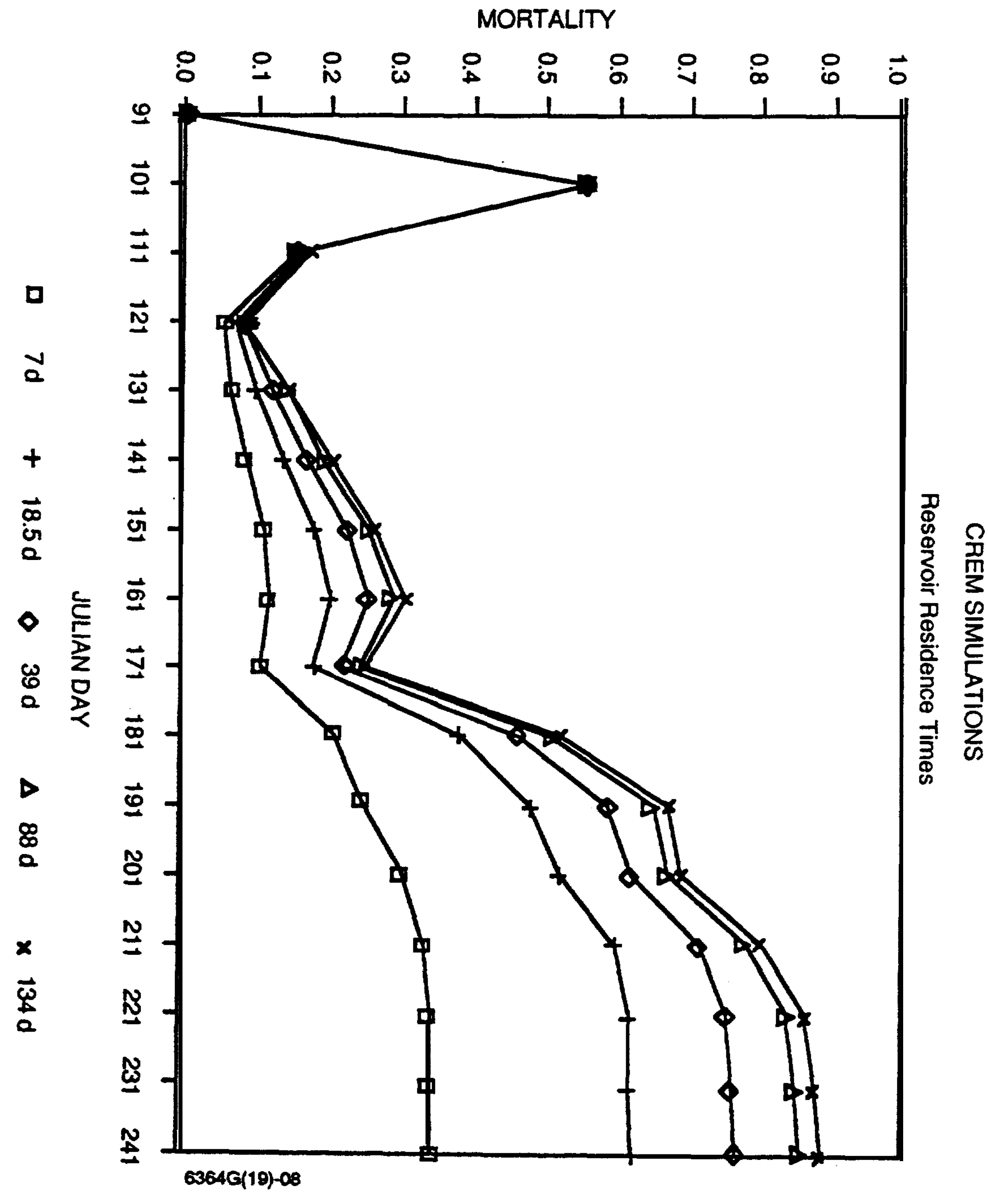

CREM SIMULATIONS
Reservoir Residence Times
MORTALITY
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
91
101
111
121
131
141
151
161
171
181
191
201
211
221
231
241
JULIAN DAY
6364G(19)-08
7 d
18.5 d
39 d
88 d
134 d

Figure 8.

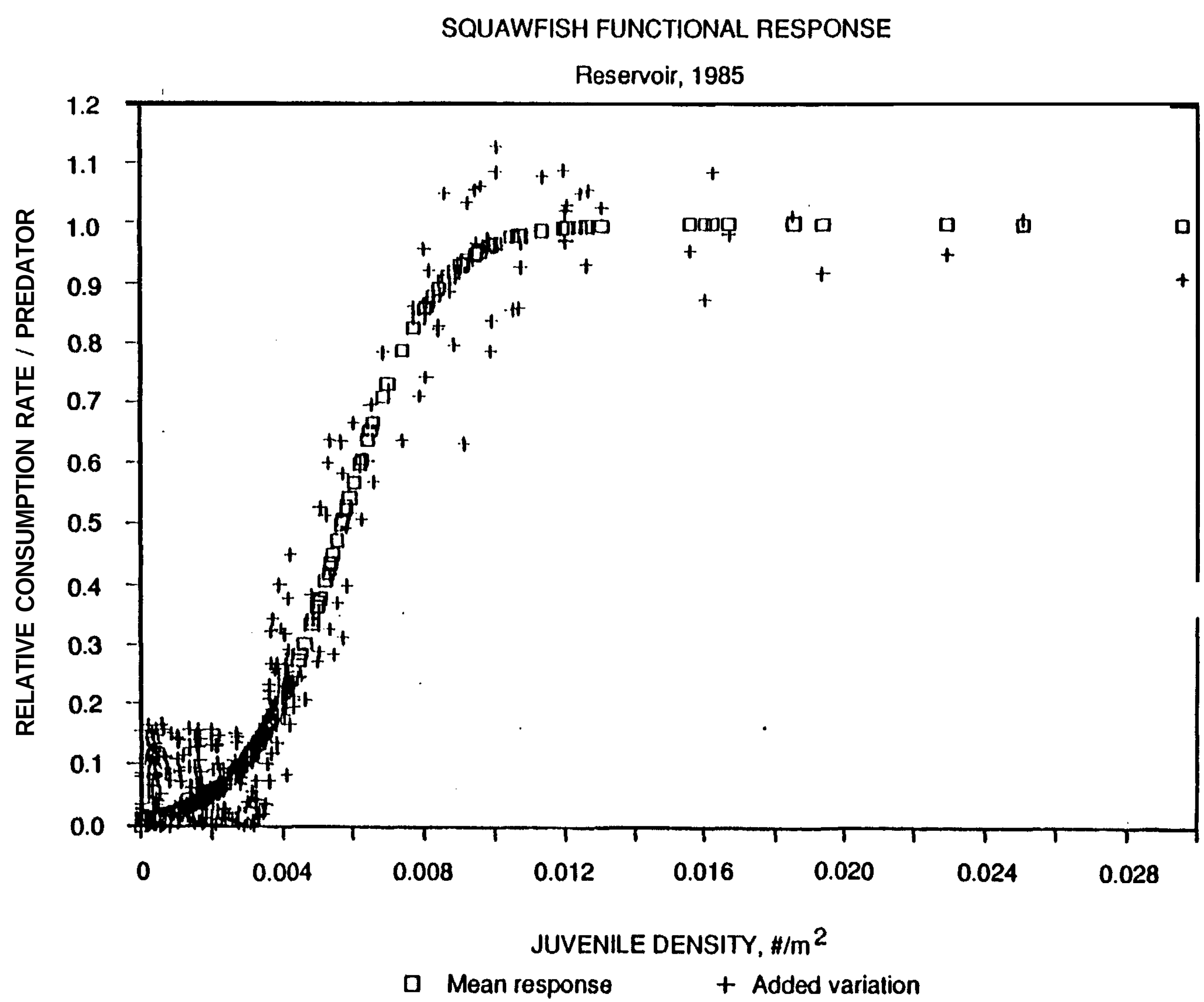

SQUAWFISH FUNCTIONAL RESPONSE
Reservoir, 1985
RELATIVE CONSUMPTION RATE / PREDATOR
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
0.004
0.008
0.012
0.016
0.020
0.024
0.028
JUVENILE DENSITY, #/m2
Mean response
Added variation

Figure 9-A.

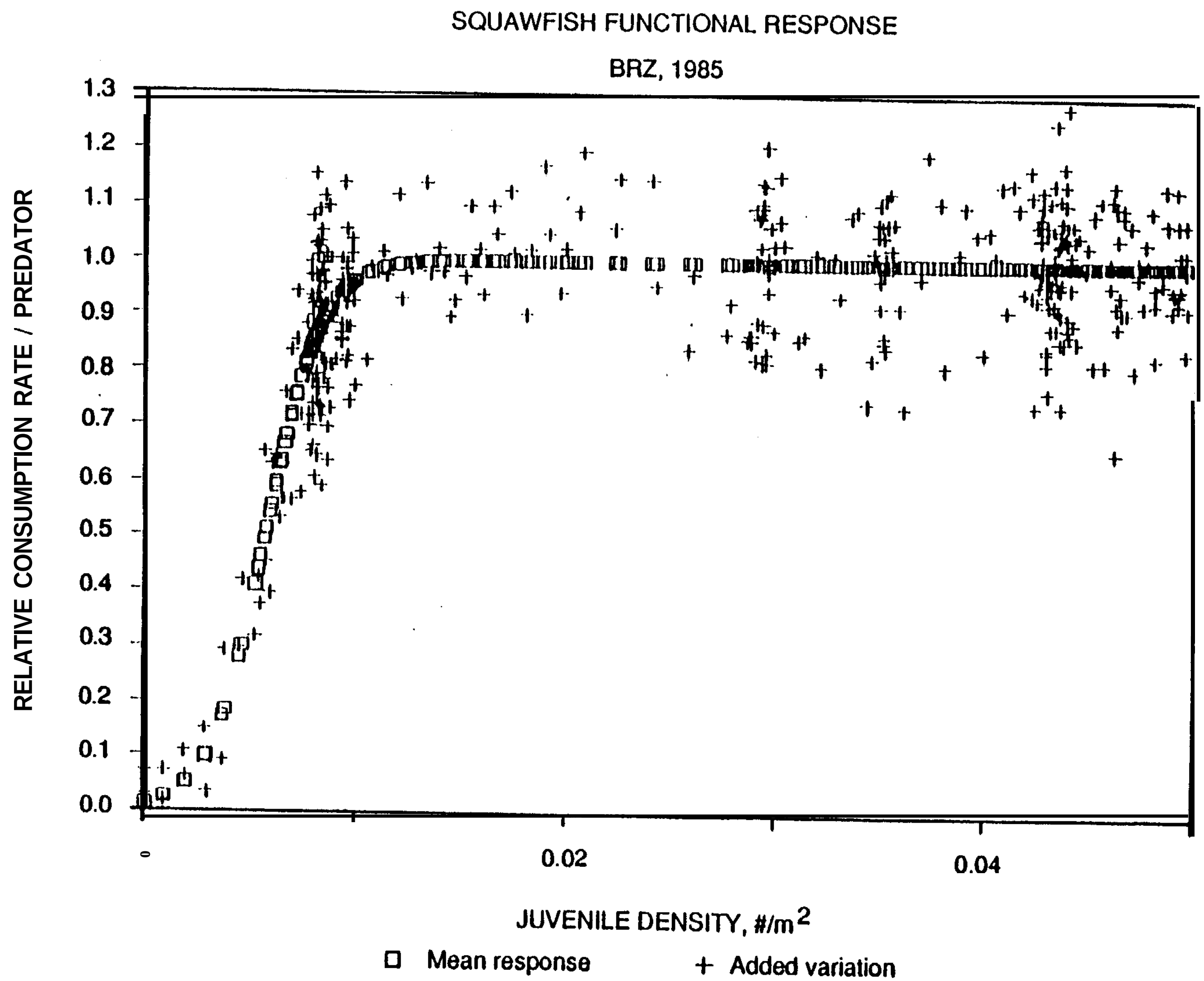

SQUAWFISH FUNCTIONAL RESPONSE
BRZ, 1985
RELATIVE CONSUMPTION RATE / PREDATOR
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
0.02
0.04
JUVENILE DENSITY, #/m2
Mean response
Added variation

Figure 9-B.

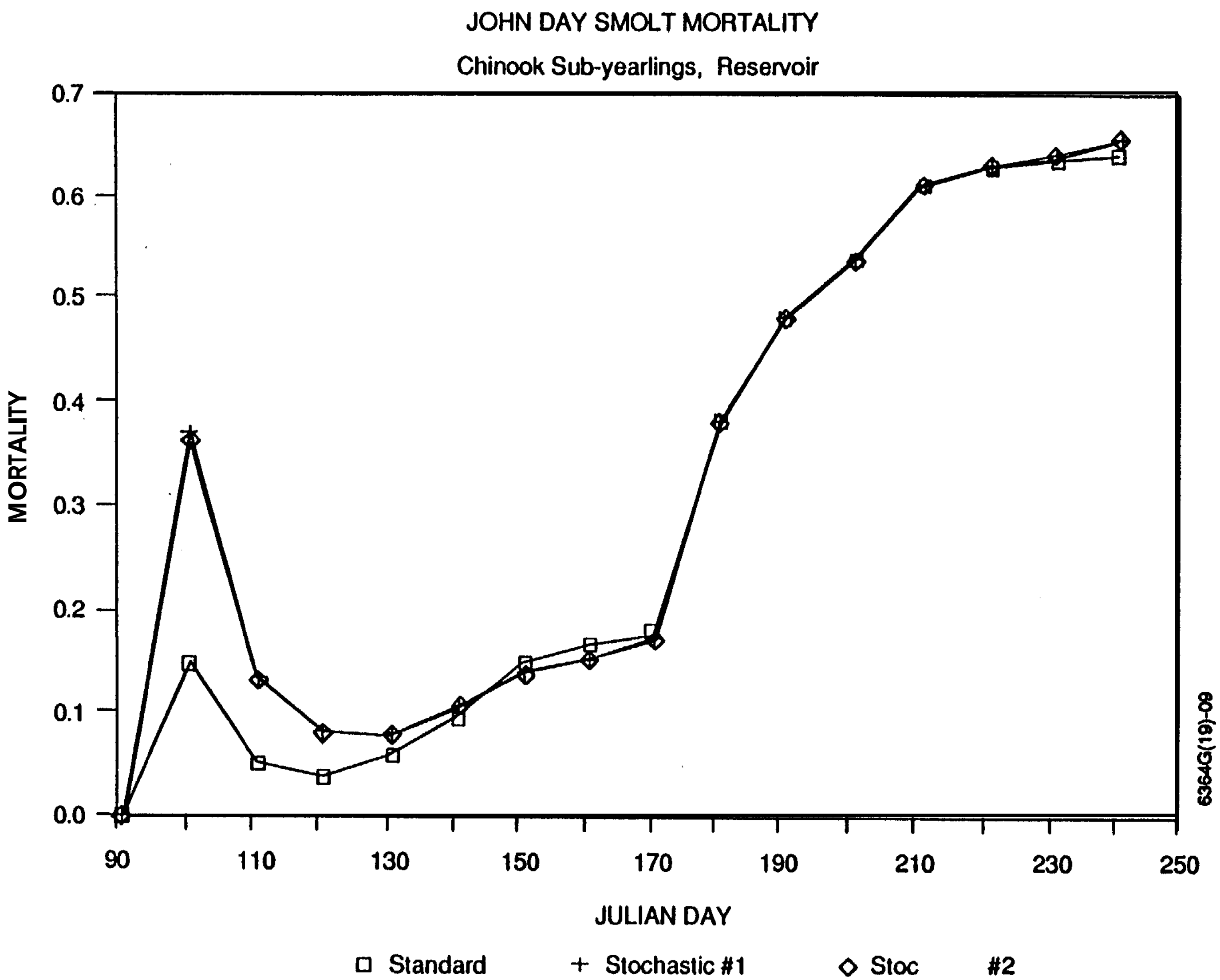

JOHN DAY SMOLT MORTALITY
Chinook Sub-yearlings, Reservoir
MORTALITY
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
90
110
130
150
170
190
210
230
250
JULIAN DAY
Standard
Stochastic #1
Stoc #2
6364G(19)-09

Figure 10.

Appendix 1. Parameter values used for simulations, in order of appearance in text. Values are dimensionless unless otherwise noted.

| Parameter | Prey # | Area # | Predator # | Value | Description |
|---|---|---|---|---|---|
| prcl | | | 1 | 5.048 | Max. consumption rate, fish/d |
| prc4 | | | 1 | 21.1 | Temp. at max. consumption rate, deg. C. |
| prc5 | | | 1 | 2.0 | 1st shape param. (gg), eq. 7 |
| prc6 | | | 1 | 15.0 | 2nd shape param. (gg), eq. 7 |
| prc2 | | | 1 | 82.6 | 1st shape param. (sg), eq. 10 |
| prc3 | | | 1 | 774. | 2nd shape param. (sg), eq. 10, $(\text{fish} / m^2)^{-1}$ |
| psp1 | | | 1 | 0.2 | Min. value for spawning attenuation of consumption |
| psp2 | | | 1 | -0.5 | Fg value at inflection point of sp, g/d |
| psp3 | | | 1 | 1.0 | Increase in Fg required to raise sp to 0.9, g/d |
| pa | | 1 | | $4.6 \times 10^5$ | Area of BRZ, $m^2$ |
| pa | | 2 | | $2.1 \times 10^8$ | Area of reservoir, $m^2$ |
| prt1 | 1 | 2 | | 21.0 | Residence time for sub-yearling chinook, d |
| prtl | 2-5 | 2 | | 4.0 | Residence time for other salmonids, d |
| prt2 | 1 - 5 | 1 | | 10.0 | Mean depth of BRZ, for velocity proportional residence time, m |

Appendix D-2

# Columbia River Ecosystem Model
# Version 2.04

## Program listing, input data and example output

Incorporating

- dynamic fishing mortality
- movement among reservoir areas by predators
- stochastic variability in parameters and driving functions
- complex reservoir area structure and **salmonid** migration route

```
      program crem204
c Ver 2.04, 8/31/89:
c++   --1.1, 1.3 Fishery mortality-- Effort & catchabilities
c++   --1.2 Equilibrium densities by area, migration coefficients
c     --1.4, 1.5 Expand number of fish species/size categories, add PSV's
c           for predator weights, add energetics eqn. for growth, add
c           reproduction, add who-eats-whom matrix & diet quality
c     --1.6 (missing)
c++   --1.7 Option for stochastic variation of params & forcing funcs
c++   --1.8 Save final PSV's for re-initialisation
c     --1.9 (not here)
c++   --1.10 Add loop for manual param modification
c Ver 1.3, 3/24/89:
c     -- Modification to provide for stochastic functional response
c        to prey density-- substitute function stosig for sigmo in
c        subroutine isv
c     -- Add printout of position on functional response curve--
c        "predator efficiency"
c Ver 1.2, 2/6/89:
c     --Modification to allow repeated simulations with one parameter
c       read from file 'times.dat', intended to perform stochastic
c       simulation of residence time, output on unit 3, mortality
c       of juv sp. 1 in area 2 (sub-yearling chin in reservoir)
c Ver 1.1, 6/21/88:
c     --Juveniles defined as numbers in area, convert to density
c        for functional response (modified der)
c     --Modify functional response to include temp effect & sigmoid
c       curve
c     --Change to Mm^3/da units for passage file, convert MI to passage
c       numbers with Vigg regression
c     --Add velocity threshold for predation
c     --Add spawning effect on functional response
c     --Add cumulative mortality calculation and printout
c Columbia River Ecosystem Model, Predation, Ver 1.0
c Incorporates Ver 0.9 to allow input of predator numbers by
c type, area and month for check of consumption against time invariant
c model-- File name 'pdfil' contains name of file with time series
c of predator numbers by type and area
c Note subscript order conventions for psv's as follows:
c Juveniles: Jv(species,area)
c Predators: Pn(species,area)
c Consumption rate: Cn(juv. sp.,area,pred. sp.)
c Per capita consumption: Cp(pred. sp.,area)
      real vp(240)
      logical debug, deriv
$INCLUDE: 'cremfil.cmn'
      real sav(240)
      character*72 runame
$INCLUDE: 'Crem204.cmn'
      clockf(i1,i2,i3,i4)=3600.*i1+60.*i2+i3+i4/100.
      call getdat(iyr,imon,iday)
      call gettim(ihr,imin,isec,il00)
```

```
      et=clockf(ihr,imin,isec,i100)
      open(5,FILE='simpar.dat')
      open(3,FILE='crem.out')
      read(5,1100)runame
      read(5,100)ne,np,nisv,na,njv,npd,debug,deriv,t1,t2,tp,dtt
      read(5,*)nrpt
      write(*,200)iyr,imon,iday,ihr,imin,isec
      write(*,1100)runame
      write(*,1100)
      write(*,300)ne,np,nisv,na,njv,npd,debug,deriv,t1,t2,tp,dtt
      if(nrpt.ne.1)write(*,*)'Repeated simulation,',nrpt,' times'
      read(5,800)n1,(n2(i),i=1,n1)
      write(*,900)n1,(n2(i),i=1,n1)
      write(3,1000)iyr,imon,iday,ihr,imin,isec,n1,(n2(i),i=1,n1)
      read(5,700)dfil,tfil,ffil,pfil,gfil,pdfil
      write(*,*)' Data file names: ',dfil,tfil,ffil,pfil,gfil,pdfil
      call init(vp,ne,0.)
      call init(psv,ne+1,0.)
      read(5,400)(psv(i),i=32,56)
      write(*,*)' Initial conditions read'
c Save initial conditions in order to restart simulation
      call copy(psv,sav,ne)
c Open file with residence times if repeated simulation
      if(nrpt.ne.1) open(9,file='times.dat')
c     write(*,500)(psv(i),i=32,56)
c     read(5,400) (F(i),i=2,8)
      close (5)
c     write(*,*)' Loc 5, debug,dtt ',debug,dtt
      call input(debug,deriv)
c     write(*,*)' Loc 6, debug,dtt ',debug,dtt
      if(nrpt.eq.1)write(*,600)
c Iterate on number of repeated simulations
      do 10 i=1,nrpt
      call copy(sav,psv,ne)
      if(nrpt.ne.1) read(9,*)ii,prt1(1,2)
      t=t1-tp
1     t=t+tp
      call output(t,vp,debug,deriv)
      call integ(t,t+tp,vp,dtt)
      if(t*1.00001.lt.t2) go to 1
10    continue
      close (3)
      call gettim(ihr,imin,isec,i100)
      et=clockf(ihr,imin,isec,i100)-et
      write(*,*)' Elapsed time: ',et,' seconds'
100   format(6i5,2l2,4f5.0)
200   format(////10x,'*****************************************'/10x,
     + '*  Columbia River Predation Simulator  *'/10x,
     + '*               Ver. 2.04               *'/10x,
     + '*     Stochastic Functional Response   *'/10x,
     + '*     Fishing Effort and Mortality     *'/10x,
     + '*     Inter-area Predator Migration    *'/10x,
```

```
     + '*    '6i5,4x,'*'/10x,
     + '*****************************************'//)
300     format(5x,' No. of equations = ',i3,', No. of parameters = ',
     +  i5/5x,' No. of isv''s = ',i3,', No. of areas = ',i3/5x,
     + ' No. of prey types = 'i3,', No. of pred. types = ',
     +  i3/5x,' Debug output? ',l2,', Derivative output? ',l2/5x,
     + ' Start time = ',f10.5,', End time = ',f10.5/5x,
     + ' Print interval = ',f10.5,', Integration step size = ',f10.5//
     +)
600   format(/10x,' Time, Driving variables,'/18x,'PSV''s'/)
400   format(10e6.0)
500   format(5g12.4)
700   format(6a12)
800   format(21i3)
900   format(5x,i5,' psv''s for CREM.OUT: '20i3)
1000 format('CREM 1.1 '6i5/21i3)
1100 format(a72)
      end
c-----------------------------------------------
      subroutine input(debug,deriv)
      character*10 nmp
      logical debug,deriv
      common/stopred/nfq,pdrate(10),freq(10)
$INCLUDE: 'cremfil.cmn'
$INCLUDE: 'Crem204.cmn'
      call init(par,np,0.)
      call init(isv,nisv,0.)
      call init(nj,25,0.)
      open(2,FILE=dfil)
c read area adjacency matrix, nj
      read(2,*)
      read(2,1200) nj
      write(*,1300) nj
      read(2,*)
      read(2,*)
      write(*,400)
      ii-0
1     ii=ii+1
      read(2,100)i,j,k,l,nmp,p
      write(*,200)ii,i,nmp,j,k,l,p
c read parameters
      go to (21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,
     >39,40) i
21    pa(j)=p
      go to 99
22    pg(l)=p
      go to 99
23    prt1(j,k)=p
      go to 99
24    prt2 (j ,k)=p
      go to 99
25    prc1(l)=p
```

```
      go to 99
26    prc2(l)=p
      go to 99
27    prc3(l)=p
      go to 99
28    prc4(l)=p
      go to 99
29    prc5(l)=p
      go to 99
30    prc6(l)=p
      go to 99
31    pmt(l)=p
      go to 99
32    pvt=p
      go to 99
33    psp1(l)=p
      go to 99
34    psp2(l)=p
      go to 99
35    psp3(l)=p
      go to 99
36    psf(l)=p
      go to 99
37    psd=p
      go to 99
38    pq(l)=p
      go to 99
39    pPn(k,l)=p
      go to 99
40    pmg(l)=p
99    if(.not.eof(2)) go to 1
      close(2)
      write(*,500) ii
      open(4,FILE=tfil)
c     read(4,300)
2     read(4,300)i,tday(i),temp(i)
c     write(*,300)i,tday(i),temp(i)
      if(.not.eof(4)) go to 2
      ntemp=i
      close(4)
      write(*,600)ntemp
      open(4,FILE=ffil)
c     read(4,300)
3     read(4,300)i,fday(i),flow(i)
c convert flow from Mm^3/da to m^3/da
      flow(i)=flow(i)*1.E6
      if(.not.eof(4)) go to 3
      nflow=i
      close(4)
      write(*,700)nflow
C Read passage file (pfil)
      open(4,FILE=pfil)
```

```
c      read(4,300)
4      read(4,300)i,jday(i),(juv(j,i),j=1,njv)
C Convert migration index to passage numbers
       do 50 j=1,njv
50     juv(j,i)=juv(j,i)*1.748
       if(.not.eof(4)) go to 4
       njp=i
       close(4)
       write(*,800)njp
C Read gonad file (gfil)
       open(4,FILE=gfil)
c      write(*,*)' npd= ',npd
6      read(4,300)i,gday(i),(gonad(j,i),j=1,npd)
c      write(*,*)i,gday(i),(j,gonad(j,i),j=1,npd)
       if(.not.eof(4)) go to 6
       ngon=i
       close(4)
       write(*,1000)ngon
c read predator effort file by type and area, if present
       pdday(1)=-1.
       if(pdfil.ne.'            ')then
         open(4,FILE=pdfil)
         i=0
5        i=i+1
         read(4,900)pdday(i),((predef(j,k,i),j=1,5),k=1,5)
c        write(*,*)pdday(i),((predef(j,k,i),j=1,5),k=1,5)
         if(.not.eof(4)) go to 5
         npdf=i
         close(4)
         write(*,1100)npdf
       endif
c set up stochastic predation empirical distribution
       nfq=psf(3)
       do 60 i=l,nfq
       j=2*i+2
       pdrate(i)=psf(j)
60     freq(i)=psf(j+1)
c initialize ran
       dl=ran(psd)
100    format(4i5,5x,a10,e10.4)
200    format(1x,2i5,1x,a10,'(',3i2,') =',g18.6)
300    format(i5,f5.0,6f10.2)
400    format(2x,'Recd Blk Param       Ndx   Value'/1x,44('-'))
500    format(' Parameter input complete',i5,' recds')
600    format(' Temperature input complete',i5,' recds')
700    format(' Flow input complete',i5,' recds')
800    format(' Passage input complete',i5,' recds')
900    format(f5.0/(10e5.0))
1000   format(' Gonad increment input complete',i5,' recds')
1100   format(' Predator effort input complete',i5,' recds')
1200   format(5f2.0)
1300   format(' Area adjacency matrix'/(1x5f5.2))
```

```
      return
      end
c-------------------------------------------------
      subroutine output(t,vp,debug,deriv)
$INCLUDE: 'cremfil.cmn'
      real vp(205),d1(5,5),d3(5)
      logical debug,deriv
$INCLUDE: 'Crem204.cmn'
      data d1/25*0./
      if(nrpt.eq.1) then
      call force(t)
      write(*,100)t,(F(i),i=2,8),ef(1,2),(Fg(i),i=1,npd)
      write(*,200)(psv(i),i=2,ne+1)
C Calculate total mortalities and print (Jv(i,6) has cum passage)
      do 10 i=1,njv
      d3(i)=0.
      do 10 j=1,na
      if (Jv(i,6).ne.0.) d1(i,j)=sum33(Cn,i,j,npd)/Jv(i,6)
10    d3(i)=d3(i)+d1(i,j)
      write(*,500)(j,(d1(i,j),i=1,5),j=1,na)
      write(*,600)'T',d3
      write(*,700)(j,j=1,na),(i,(Cp(i,j),j=1,na),i=1,npd)
      call init(Cp,25,0.)
c      write(3,150)t,(psv(n2(i)),i=1,n1)
c      write(3,150)t,(Jv(i,6),i=1,njv),((d1(i,j),i=1,njv),j=1,na)
      write(3,150)t,Fs,Fl,Ft,Fg(1),((d1(i,j),i=1,njv),j=1,na),d2
c     write(*,*)' Loc 1',deriv,debug
      if(deriv) then
c     write(*,*)' Loc 2'
      call der(t,vp)
      write(*,300)
      write(*,200) (vp(i),i=l,ne)
      endif
      if(debug) then
      write(*,400) (isv(i),i=2,nisv+1)
      endif
c     write(*,*)' Loc 3'
100   format{/*   Time    Chin 0   Chin 1 Steelhd Coho
     >'Sockeye Flow    Temp Efrt12'/1x,f6.2,4x,8g8.3/
     >1x,'Gonad inc '5g9.3/)
200   format(/' Prey Chin 0      Chin 1      Steelhd
     >'Coho         Sockeye*/* Area 1',5g12.4/6x'2',5g12.4/6x'3',5g12.4/
     >6x,'4',5g12.4/6x,'5',5g12.4/' TotPsg'5g12.4/
     >' Pred Squaws'/* Area 1',5g12.4/
     >6x,'2',5g12.4/6x,'3',5g12.4/6x,'4',5g12.4/6x,'5',5g12.4/
     >' Cons  Chin 0      Chin 1      Steelhd    Coho         Sockeye*/
     >' squw 1',5g12.4/4(7x,5g12.4/),6x'2'5g12.4/4(7x,5g12.4/),6x'3'
     >5g12.4/4(7x,5g12.4/),6x'4'5g12.4/4(7x,5g12.4/),6x'5'5g12.4
     >/(7x,5g12.4))
150   format(21e12.4)
300   format(1x,'Derivatives')
400   format(1x,'Intermediate System Variables'/(7x,5g12.4))
```

```
500   format(' mort '/' Area', i2,5g12.4/(5x,i2,5g12.4))
600   format(6x,a1,5g12.4)
700   format(/' Per capita consumption by area*/* Area'2x,i7,4i12/
     >' Pred'i2,5g12.4/(5xi2,5g12.4))
      return
      endif
      write(*,*)t,prt1(1,2),sum33(Cn,1,2,npd)/Jv(1,6)
      return
      end
c---------------------------------------------------
      subroutine  integ(t1,t2,vp,dtt)
      dimension vp(205)
$include: 'Crem204.cmn'
c     write(*,*)' integ: t1,t2,dtt ',t1,t2,dtt
      n=(t2-t1)/dtt+.001
      t=t1-dtt
      do 20 i=1,n
      t=t+dtt
      call der(t,vp)
      do 20 j=1,ne
      psv(j+l)=psv(j+l)+vp(j)*dtt
      if (psv(j+l).le. l.e-10) psv(j+l)=0.0
c       write(*,*)'Neg psv at time ',t,', psv(',j,')=',psv(j+1)
20    continue
      return
      end
c---------------------------------------------------
      subroutine der(t,vp)
      real vp(205)
$INCLUDE: 'Crem204.cmn'
c functions to calculate equivalent linear subscripts for
c 2 & 3 dimensioned arrays-- these work only for dimensions
c of (5,5) and (5,5,5) and must be modified if array
c dimensions are changed
      ij(i,j)=(j-1)*5+i
      ijk(i,j,k)=ij(i,j)+(k-1)*25
c     write(*,*)' Loc 21'
c Find driving function values
      call force(t)
c     write(*,*)' Loc 22'
c Find intermediate variable values
      call isvt(t)
c Calculate derivatives
c     write(*,100)t
100   format(' Derivatives being calculated at t ='
     >,f10.4)
c Prey migration and consumption
      do 10 i=l,njv
C Calc deriv's of Jv, area 1:
      vp(ij(i,1))=Fs(i)-Jv(i,1)/rt(i,1)-sum33(rc,i,1,npd)
      do 10 j=2,na
c Sum contributions from other areas according to
```

```
c proportions in adjacency matrix, nj
      d3=0.
      do 50 k=1,na
50    if((nj(j,k).gt.0.).and.(nj(j,k).le.l.))   d3=d3+
     >nj(j,k)*Jv(i,k)/rt(i,k)
C Calc deriv's of Jv, areas 2 - na:
10    vp(ij(i,j))=d3-Jv(i,j)/rt(i,j)-sum33(rc,i,j,npd)
c Predator mortality and consumption audit
      do 20 i=1,npd
      do 20 j=1,na
c calc net migration
      d3=0.
      do 40 k=l,na
40    d3=d3+mg(j,k,i)*Pn(i,k)
C Calc deriv's of Pn:
      vp(ij (i,j)+30)=-(pmt(i)+pq(i)*ef(i,j))*Pn(i,j)+d3
      do 20 k=1,njv
c     write(*,400)i,j,k,ijk(i,j,k)
C Calc deriv's of Cn:
20    vp(ijk(k,j,i)+55)=rc(k,j,i)
C Calc deriv's of cum passage in Jv(i,6):
      do 30 k=1,njv
30    vp(ij (k,6) )=Fs(k)
c Calc per capita consumption
      do 60 i=1,npd
      do 60 j=l,na
60    vp(ij(i,j)+180)=sum31(rc,j,i,njv)/Pn(i,j)
c     write(*,300)(psv(i),i=2,ne+1)
c     write(*,200)(vp(i),i=1,ne)
c300   format(' Der-- psv''s'/(5g12.4))
c200   format(' Der-- dpsv''s'/(5g12.4))
400   format('  Der-- indices'/5i5)
      return
      end
c-------------------------------------------------
      subroutine force(t)
c Find instantaneous forcing function values from
c incremental time series
$INCLUDE: 'Crem204.cmn'
      data i1/2/,i2/2/,i3/2/,i4/1/,i5/2/
c     write(*,100)t
100   format(' Forcing functions being calculated at t ='
     >,f10.4)
C temperature
c assumes that flow rate is characteristic of midday (hence, t-.5)
      do 10 i=i1,ntemp
      if (tday(i).ge.t) go to 1
10    continue
      i=ntemp
1     j=i-1
      i1=max(i-2,2)
      Ft=xlin(temp(j),temp(i),tday(j),tday(i),t-.5)
```

```
c Flow rate
c assumes that flow rate is characteristic of midday (hence, t-.5)
      do 20 i=i2,nflow
      if (fday(i).ge.t) go to 2
20    continue
      i=nflow
2     j=i-1
      i2=max(i-2,2)
      Fl=xlin(flow(j),flow(i),fday(j),fday(i),t-.5)
c Juvenile passage rates
      do 30 i=i3,njp
      if (jday(i).ge.ifix(t+1.0001)) go to 3
30    continue
      i=njp
3     j=i
      i3=max(i-2,2)
      do 40 k=1,njv
40    Fs(k)=juv(k,j)
c Gonad sizes
      do 60 i=i5,ngon
      if (gday(i).ge.t) go to 4
60    continue
      i=ngon
4     j=i-1
      i5=max(i-2,2)
      do 70 k=l,npd
70    Fg(k)=xlin(gonad(k,j),gonad(k,i),gday(j),gday(i),t)
c Setup effort levels if data present (pdday(l).ne.-1.)
      if(t.eq.pdday(i4)) then
      do 50 i=1,5
      do 50 j=1,5
50    ef(i,j)=predef(i,j,i4)
      i4=i4+1
      endif
      return
      end
c-----------------------------------------------------------
      subroutine isvt(t)
$INCLUDE: 'Crem204.cmn'
c     write(*,100)t
100   format(' ISVs being calculated at t ='
     >,f10.4)
c Residence times
      do 10 i=1,njv
      do 10 j=1,na
      rt(i,j)=prt1(i,j)+prt2(i,j)*pa(j)/Fl
      if (rt(i,j).le.0.) then
         write(*,*) 'rt:',i,j,rt
      endif
10    continue
c Total prey densities by area
      do 30 j=1,na
```

```
      tJv(j)=0.
      do 40 i=1,njv
40    tJv(j)=tJv(j)+Jv(i,j)
30    tJv(j)=tJv(j)/pa(j)
C Consumption rates
c     if(t.ge.96.55)write(*,*)'t=',t
      do 90 k=1,npd
C ct calculates temperature effect on functional response
      ct=prc1(k)*gg(Ft,0.,prc4(k),prc5(k),prc6(k))
c sp is spawning effect on functional response
      sp=psp1(k)+(1.-psp1(k))*at(Fg(k),psp2(k),psp3(k))
c     if(t.ge.96.55)write(*,*)' k=',k,', ct=',ct,', sp=',sp
      do 20 j=na,1,-1
C ePn is *effective predator density' due to water velocity threshold, pvt
      ePn=sw(Pn(k,j),0.,pvt-Fl/pa(j))
      d2=sigmo(tJv(j),prc2(k),prc3(k))
      if (psf(2).le.0.) then
          d1=ct*d2*ePn*sp
      else
          d1=ct*stosig(d2,tJv(j),psf)*ePn*sp
      endif
c     if(t.ge.96.55)write(*,*)'j=',j,', ePn=',ePn,', d1=',d1
      do 20 i=1,njv
C rc is temp effect X func. resp.(total prey) X ePn X prop. of prey sp.
      if (tJv(j).gt.0.) then
         rc(i,j,k)=dl*Jv(i,j)/(pa(j)*tJv(j))
      else
         rc(i, j,k)=0.
      endif
c     if (t.ge.96.55)write(*,*)'i=',i,', rc=',rc(i,j,k),Jv(i,j),pa(j)
20    continue
c migration rates, adjacency matrix designates non-zero migration isv's
c sum predators
      tPn=sum22(Pn,k,na)
      do 70 j=1,na
      do 70 i=1,na
      if (nj(i,j).gt.0) then
        d3=pmg(k)/(sqrt(pa(i))+sqrt(pa(j)))
        mg(j,i,k)=d3*sw(1.,0. ,pPn(k,j)-(Pn(k,j) /tPn) )
70    endif
c calc diagonal term to ensure conservation
      do 50 i=1,na
      d3=0.
      do 60 j=1,na
60    if (i.ne.j) d3=d3+mg(j,i,k)
50    mg(i,i,k)=-d3
90    continue
cl0    write(*,200)i,j,k,rc(i,j,k)
c200   format(' isv, (i,j,k) = '3i2', rc = 'g12.4)
      return
      end
C-----------------------------------------
```

```
      real function arr(T, P1,P2)
      arr= (10**(p1*T+p2))*.69315
      return
      end
C-----------------------------------------
      real function at(x,p1,p2)
      parameter (pi=3.14159)
      TK=tan(.2*pi)/(p2-p1)
      at=2./pi*atan(TK*(x-p1))+.5
      if (at.lt. 0.) at=0.
      return
      end
C-----------------------------------------
      real function sw(x,y,z)
      sw=x
      if (z.le.0.) sw=y
      return
      end
C-----------------------------------------
      real function xlin(y1,y2,x1,x2,x)
      xlin=y1+(y2-y1)*((x-x1)/(x2-x1))
      return
      end
C-----------------------------------------
      subroutine init(x,n,p)
      real x(1)
      do 10 i=1,n
10    x(i)=p
      return
      end
C-----------------------------------------
      subroutine ninit(m,n,j)
      integer m(1)
      do 10 i=1,n
10    m(i)=j
      return
      end
C-----------------------------------------
      real function sum22(x,i,n)
c Sums a doubly subscripted array, x, over n values
c the second index, for i the first index
      real x(5,5)
      s=0.
      do 10 k=1,n
10    s=s+x(i,k)
      sum22=s
      return
      end
C-----------------------------------------
      real function sum33(x,i,j,n)
c Sums a triply subscripted array, x,over n values of
c the third index, for i,j the first & second indices
```

```
      real x(5,5,5)
      sum=0.
      do 10 k=1,n
10    sum=sum+x(i,j,k)
      sum33=sum
      return
      end
C--------------------------------------------------
      real function sum31(x,j,k,n)
c Sums a triply subscripted array, x, over n values of
c the first index, for j,k the second & third indices
      real x(5,5,5)
      sum=0 .
      do 10 i=1,n
10    sum=sum+x(i,j,k)
    sum31=sum
      return
      end
C--------------------------------------------------
      real function gg(x,a,b,c,d)
c Generalised Gamma function
      x1=(x-a)/(b-a)
      gg=x1**c*exp((c/d)*(1.-x1**d))
      return
      end
C--------------------------------------------------
      real function sigmo(x,a,b)
C Sigmoid function, asymptote is 1.0
c Artificially force through (0.,0.)
c Stretch to range (0.,1.) [No-- commented out]
      sigmo=0.
      if(x.le.0.) return
c      c=l./a
      sigmo=1./(1.+a*exp(-b*x))
c      sigmo=(1.+c)*sigmo-c
      return
      end
C--------------------------------------------------
      subroutine copy(x,y,n)
      real x(1),y(1)
      do 10 i=1,n
10    y(i)=x(i)
      return
      end
c--------------------------------------------------
      real function stosig(xmu,x,ps)
c Generates stochastic functional response curve
      dimension ps(1)
      common/stopred/nfq,pdrate(10),freq(10)
      if (x.gt.ps(1)) then
          d1=xmu+gauss(0.,ps(2))
          stosig=dl
```

```
          return
       else
          dl=emp(pdrate,freq,nfq)
       endif
       stosig=d1
       return
       end
c----------------------------------------------------------------
       real function gauss(xmu,sd)
1      x1=ran(0.)
       x2=ran(0.)
       c1=sin(6.283185*x1)*sqrt(-2.*alog(x2))
       gauss=c1*sd+xmu
       return
       end
c----------------------------------------------------------------
       real*4 function ran(x)
c Pseudo-random number generator, mid-square method,
c double precision generation, single precision result
c repeat interval 2 - 5e5, depending on seed!
       real*8 y
       if(x.ne.0.) then
         seed=x
         y=x
       ran=y
         return
       endif
       y=y*seed*1.e5
       y=y-float(ifix(y))
       ran=y
       return
       end
c----------------------------------------------------------------
       real function emp(x,y,n)
c Generates random number from empirical distribution
c given by x,y histogram with n-l bars, assumes
c sigma(y)=1.0, n>1, x strictly monotonic increasing
       dimension x(1) ,y(1)
       z=ran(0.)
       sum=0.
       do 10 i=2,n
       sum=sum+y(i)
       if (z.le.sum) go to 1
10     continue
       i=n
1      ii=i-1
       emp=x(ii)+ran(0.)*(x(i)-x(ii))
       return
       end
```

Common file crem204.cmn:

```
      common/drvr/F(1),Fs(5),Fl,Ft,Fg(5)
      common/psv/psv(1) ,Jv(5,6) ,Pn(5,5) ,Cn(5,5,5) ,Cp(5,5)
      real Jv
      common/isv/isv(1),rt(5,5),rc(5,5,5),tJv(5),ef(5,5),
     >ct,ePn,sp,tPn,mg(5,5,5)
      real isv,mg
      common/par/par(1) ,pa(5) ,pq(5) ,prt1(5,5) ,prt2(5,5) ,prc1(5),
     >prc2(5),prc3(5),prc4(5),prc5(5),prc6(5),pmt(5),pvt,
     >psp1(5) ,psp2(5) ,psp3(5) ,psf(15) ,psd,pq(5) ,pPn(5,5) ,pmg(5)
      common/ndx/ne,np,nisv,na,njv,npd,nrpt,d2,nj(5,5)
      real nj
      common/drvrfil/ntemp,tday(200),temp(200),nflow,fday(200),
     >flow(200),njp,jday(200),juv(5,200),pdday(6),predef(5,5,6),
     >ngon,gday(20),gonad(5,20)
      real jday,juv
```

Common file cremfil.cmn:

```
      common/fname/dfil,tfil,ffil,pfil,pdfil,gfil,n1,n2(20)
      character*12  dfil,tfil,ffil,pfil,pdfil,gfil
```

Input data file crem.dat:
(Descriptions and units of measurement for variables defined in this file may be found in the corresponding file for crem205 in Appendix 3)

Adjacency matrix:
.0.4.5.1.0
2.0..2.2.6
2..20..2.6
2..2.20..6
0.2.2.2.0.

Parameter values

| No. | 1st | 2nd | 3rd | ---- | Name | | Value |
|---|---|---|---|---|---|---|---|
| 1 | 1 | | | | pa 1 m2 | | .46E6 |
| 1 | 2 | | | | pa 2, m2 | | 166.E6 |
| 1 | 3 | | | | pa 3, m2 | | 21.E6 |
| 1 | 4 | | | | pa 4, m2 | | 21.E6 |
| 1 | 5 | | | | pa 5, m2 | | 2.336 |
| 2 | | | 1 | | pg 1 | | .228 |
| 4 | 1 | 1 | | | prt2 1 1 | | 10. |
| 4 | 2 | 1 | | | prt2 2 1 | | 10. |
| 4 | 3 | 1 | | | prt2 3 1 | | 10. |
| 4 | 4 | 1 | | | prt2 4 1 | | 10. |
| 4 | 5 | 1 | | | prt2 5 1 | | 10. |
| 3 | 1 | 2 | | | prtl 1 2 | | 18.9 |
| 3 | 2 | 2 | | | prtl 2 2 | | 3.6 |
| 3 | 3 | 2 | | | prtl 3 2 | | 3.6 |
| 3 | 4 | 2 | | | prtl 4 2 | | 3.6 |
| 3 | 5 | 2 | | | prtl 5 2 | | 3.6 |
| 3 | 1 | 3 | | | prtl 1 3 | | 18.9 |
| 3 | 2 | 3 | | | prtl 2 3 | | 3.6 |
| 3 | 3 | 3 | | | prtl 3 3 | | 3.6 |
| 3 | 4 | 3 | | | prtl 4 3 | | 3.6 |
| 3 | 5 | 3 | | | prt15 3 | | 3.6 |
| 3 | 1 | 4 | | | prtl 1 4 | | 37.8 |
| 3 | 2 | 4 | | | prtl 2 4 | | 7.2 |
| 3 | 3 | 4 | | | prtl 3 4 | | 7.2 |
| 3 | 4 | 4 | | | prtl 4 4 | | 7.2 |
| 3 | 5 | 4 | | | prtl 5 4 | | 7.2 |
| 3 | 1 | 5 | | | prtl 1 5 | | 1. |
| 3 | 2 | 5 | | | prtl 2 5 | | 1. |
| 3 | 3 | 5 | | | prtl 3 5 | | 1. |
| 3 | 4 | 5 | | | prtl 4 5 | | 1. |
| 3 | 5 | 5 | | | prtl 5 5 | | 1. |
| 5 | | | 1 | | prcl | 1 | 5.048 |
| 6 | | | 1 | | prc2 | 1 | 82.626 |
| 7 | | | 1 | | prc3 | 1 | 774.14 |
| 8 | | | 1 | | prc4 | 1 | 21.1 |
| 9 | | | 1 | | prc5 | 1 | 3. |
| 10 | | | 1 | | prc6 | 1 | 15. |
| 11 | | | 1 | | pmt | 1 | 1.353-4 |
| 12 | | | | | pvt | | 8.6434 |
| 13 | | | 1 | | psp1 | 1 | .2 |

```
14          1   psp2    1        -.5
15          1   psp3    1         1.
16          1   psf     1     .0035
16          2   psf     2       .00 .11
16          3   psf     3        4.
16          4   ps f    4        0.
16          5   ps f    5      .267
16          6   psf     6      .015
16          7   psf     7      .267
16          8   psf     8      .105
16          9   ps f    9      .433
16         10   psf    10      ,165
16         11   psf    11      ,233
16         12   psf    12      .230
16         13   psf    13      .067
17              psd         .43215
18          1   pq
19      1   1   pPn  1 1 1  .293e-3 .03300
19      1   2   pPn  1 2    .76300
19      1   3   pPn  1 3    .09700
19      1   4   pPn  1 4    .09700
19      1   5   pPn  1 5    .01000
20          1   pmg  1         .05
```

Input data file for simulation parameters, **simpar.dat:**

```
 Five areas, migration, no fishing, lx forebay squaw conc., 1 day in fb
  205   162   309     5     5'   1 F F  91.  241.  10.   .01
1
 10 27  28  29  30  31  62  63  64  65  66
crem.dat     temp85.dat  flow85.dat pass85.dat  gonad.dat   effrt.dat
2800.0    0.     0.     0.     0.64698.     0.     0.     0.     0.
8200.0    0.     0.     0.     0.8200.0     0.     0.     0.     0.
902.00    0.     0.     0.     0.
```

Output file (standard output -- executed on 80386 computer, 25 Mhz-, with coprocessor):

```
****************************************
*  Columbia River Predation Simulator  *
*              Ver. 2.04               *
*     Stochastic Functional Response   *
*     Fishing Effort and Mortality     *
*     Inter-area Predator Migration    *
*    1990  10  22  16  50  56          *
****************************************
```

Five areas, migration, no fishing, lx forebay squaw conc., fb rt: l/flow

```
     No. of equations = 205, No. of parameters =   162
     No. of isv's = 309, No. of areas =   5
     No. of prey types =   5, No. of pred. types = 1
     Debug output?  F, Derivative output? F
     Start time =   91.00000, End time = 241.00000
     Print interval =   10.00000, Integration step size =     .01000

       10 psv's for CREM.OUT:   27 28 29 30 31 62 63 64 65 66

 Data file names: crem.dat    temp85.dat  flow85.dat pass85.dat gonad.dat
 effrt.dat

 Initial conditions read

Area adjacency matrix
  .00   .40   .50   .10   .00
 2.00   .00   .20   .20   .60
 2.00   .20   .00   .20   .60
 2.00   .20   .20   .00   .60
  .00  2.00  2.00  2.00   .00

 Recd Blk Param        Ndx   Value
------------------------------------------
    1    1 pa 1 m2   ( 1 0 0) =      460000.
    2    1 pa 2, m2  (2 0 0) =       .166000E+09
    3    1 pa 3, m2  (300) =         .210000E+08
    4    1 pa 4, m2  ( 4 0 0) =      .210000E+08
    5    1 pa 5, m2  (500) =         .230000E+07
    6    2 pg 1      ( 0 0 1) =      .228000
    7    4 prt2 11   ( 110) =        10.0000
    8    4 prt2 2 1  (210) =         10.0000
    9    4 prt2 3 1  (310) =         10.0000
```

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10 | 4 | prt2 | 4 | 1 | | ( 4 1 0) | = | 10.0000 |
| 11 | 4 | prt2 | 5 | 1 | | ( 5 1 0) | = | 10.0000 |
| 12 | 3 | prtl | 1 | 2 | | ( 1 2 0) | = | 18.9000 |
| 13 | 3 | prtl | 2 | 2 | | ( 2 2 0) | = | 3.60000 |
| 14 | 3 | prtl | 3 | 2 | | ( 3 2 0) | = | 3.60000 |
| 15 | 3 | prtl | 4 | 2 | | ( 4 2 0) | = | 3.60000 |
| 16 | 3 | prtl | 5 | 2 | | ( 5 2 0) | = | 3.60000 |
| 17 | 3 | prtl | 1 | 3 | | ( 1 3 0) | = | 18.9000 |
| 18 | 3 | prtl | 2 | 3 | | ( 2 3 0) | = | 3.60000 |
| 19 | 3 | prtl | 3 | 3 | | ( 3 3 0) | = | 3.60000 |
| 20 | 3 | prtl | 4 | 3 | | ( 4 3 0) | = | 3.60000 |
| 21 | 3 | prt1 | 5 | 3 | | ( 5 3 0) | = | 3.60000 |
| 22 | 3 | prtl14 | | | | (14 0) | = | 37.8000 |
| 23 | 3 | prtl | 2 | 4 | | ( 2 4 0) | = | 7.20000 |
| 24 | 3 | prtl | 3 | 4 | | ( 3 4 0) | = | 7.20000 |
| 25 | 3 | prt1 | 4 | 4 | | ( 4 4 0) | = | 7.20000 |
| 26 | 3 | prt15 | | 4 | | ( 5 4 0) | = | 7.20000 |
| 27 | 3 | prtl | 1 | 5 | | ( 1 5 0) | = | 1.00000 |
| 28 | 3 | prt1 | 2 | 5 | | ( 2 5 0) | = | 1.00000 |
| 29 | 3 | prtl | 3 | 5 | | ( 3 5 0) | = | 1.00000 |
| 30 | 3 | prtl | 4 | 5 | | ( 4 5 0) | = | 1.00000 |
| 31 | 3 | prtl | 5 | 5 | | ( 5 5 0) | = | 1.00000 |
| 32 | 5 | prcl | | | 1 | ( 0 0 1) | = | 5.04800 |
| 33 | 6 | prc2 | | | 1 | ( 0 0 1) | = | 82.6260 |
| 34 | 7 | prc3 | | | 1 | ( 0 0 1) | = | 774.140 |
| 35 | 8 | prc4 | | | 1 | ( 0 0 1) | = | 21.1000 |
| 36 | 9 | prc5 | | | 1 | ( 0 0 1) | = | 3.00000 |
| 37 | 10 | prc6 | | | 1 | ( 0 0 1) | = | 15.0000 |
| 38 | 11 | pmt | | | 1 | ( 0 0 1) | = | .135000E-03 |
| 39 | 12 | pvt | | | | ( 0 0 0) | = | 86400.0 |
| 40 | 13 | psp1 | | | 1 | ( 0 0 1) | = | .200000 |
| 41 | 14 | psp2 | | | 1 | ( 0 0 1) | = | -.500000 |
| 42 | 15 | psp3 | | | 1 | ( 0 0 1) | = | 1.00000 |
| 43 | 16 | psf | | | 1 | ( 0 0 1) | = | .350000E-02 |
| 44 | 16 | psf | | | 2 | ( 0 0 2) | = | .000000 |
| 45 | 16 | psf | | | 3 | ( 0 0 3) | = | 4.00000 |
| 46 | 16 | psf | | | 4 | ( 0 0 4) | = | .000000 |
| 47 | 16 | psf | | | 5 | ( 0 0 5) | = | .267000 |
| 48 | 16 | psf | | | 6 | ( 0 0 6) | = | .150000E-01 |
| 49 | 16 | psf | | | 7 | ( 0 0 7) | = | .267000 |
| 50 | 16 | psf | | | 8 | ( 0 0 8) | = | .105000 |
| 51 | 16 | psf | | | 9 | ( 0 0 9) | = | .433000 |
| 52 | 16 | psf | | | 10 | ( 0 010) | = | .165000 |
| 53 | 16 | psf | | | 11 | ( 0 011) | = | .233000 |
| 54 | 16 | psf | | | 12 | ( 0 012) | = | .230000 |
| 55 | 16 | psf | | | 13 | ( 0 013) | = | .670000E-01 |
| 56 | '17 | psd | | | | ( 0 0 0) | = | .432150 |
| 57 | 18 | pq | | | 1 | ( 0 0 1) | = | .293000E-03 |
| 58 | 19 | pPn | 1 | 1 | | ( 0 11) | = | .330000E-01 |
| 59 | 19 | pPn | 1 | 2 | | ( 0 1 2) | = | .763000 |
| 60 | 19 | pPn | 1 | 3 | | ( 0 1 3) | = | .970000E-01 |
| 61 | 19 | pPn | 1 | 4 | | ( 0 1 4) | = | .970000E-01 |

```
62   19 pPn  1 5   ( 0 1 5) =       .100000E-01
63   20 pmg  1     ( 0 0 1) =       .500000E-01
```

Parameter input complete 63 recds
Temperature input complete 153 recds
Flow input complete 153 recds
Passage input complete 153 recds
Gonad increment input complete 20 recds
Predator effort input complete 3 recds

Time, Driving variables,
PSV's

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrtl2 |
|---|---|---|---|---|---|---|---|---|
| 91.00 | 99.6 | 75.2 | .000 | .000 | 24.5 | .340E+09 | 5.35 | .000 |

Gonad inc .200E-02

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | .0000 | .0000 | .0000 | .0000 | .0000 |
| 2 | .0000 | 0000 | .0000 | .0000 | .0000 |
| 3 | 0000 | .0000 | .0000 | | .0000 |
| 4 | .0000 | .0000 | .0000 | .0000 | |
| 5 | .0000 | .0000 | .0000 | .0000 | .0000 |
| TotPsg | .0000 | .0000 | .0000 | .0000 | .0000 |
| Pred Squaws | | | | | |
| Area 1 | 2800. | . | .0000 | .0000 | |
| 2 | .6470E+05 | 0000 | .0000 | .0000 | .0000 |
| 3 | 8200. | .0000 | .0000 | | |
| 4 | 8200. | 0000 | .0000 | .0000 | .0000 |
| 5 | 902.0 | .0000 | .0000 | .0000 | .0000 |

| Cons | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Squw 1 | 0000 | 0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | |
| | .0000 | .0000 | .0000 | .0000 | |
| 2 | 0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | | |
| | .0000 | 0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| 3 | .0000 | .0000 | .0000 | .0000 | |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | | .0000 |
| | .0000 | 0000 | .0000 | | .0000 |
| 4 | .0000 | .0000 | .0000 | .0000 | |
| | 0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | | .0000 |
| | .0000 | .0000 | .0000 | .0000 | |
| | .0000 | .0000 | .0000 | .0000 | .0000 |

```
     5   .0000    .0000    .0000    .0000    .0000
         .0000    . 0000   .0000    .0000    .0000
         .0000    .0000    .0000    .0000    .0000
         .0000    . 0000   .0000    .0000    .0000
         .0000    .0000    .0000    .0000    .0000
         .0000    .0000    .0000    .0000    .0000
         .0000    .0000    .0000    .0000    0000
         .0000    .0000    .0000    .0000    .0000
         . 0000   .0000    .0000    .0000    .0000
         .0000    .0000    .0000    .0000    .0000
mort
Area 1   .0000    . 0000   .0000    .0000    .0000
     2   .0000    . 0000   .0000    .0000    .0000
     3   . 0000   .0000    .0000    .0000    .0000
     4   .0000    . 0000   .0000    .0000    0000
     5   . 0000   .0000    0000     .0000    .0000
     T   .0000    .0000    .0000    .0000    .0000

Per capita consumption by area
Area       1        2        3        4        5
Pred 1   .0000    .0000    .0000    .0000    . 0000

  Time   Chin 0  Chin 1 Steelhd Coho    Sockeye Flow    Temp   Efrt12
101.00  199.    .640E+05.207E+04.000    .000    .424E+097.25   .000
Gonad inc  .200E-02

Prey Chin 0      Chin  1   Steelhd    Coho       Sockeye
Area 1 1.347       762.9     12.73     .0000      .8158
     2  233.5    . 1380E+06  1705.     .0000      98.50
     3  319.1    . 1614E+06  2014.     .0000      116.5
     4  76.04    . 8830E+05  1046.     .0000      67.15
     5  14.49    .5398E+05   618.0     .0000      '37.74
TotPsg  772.6    . 6044E+06  7441.     .0000      498.2
Pred -Squaws
Area 1   2796.    .  0000       .0000     .0000     .0000
     2   .6461E+05  .0000       .0000     .0000     .0000
     3   8191.    .  0000       .0000     .0000     .0000
     4   8191.    .  0000       .0000     .0000     0000
     5   900.6     .0000        .0000     .0000     : 0000
Cons  Chin  0  Chin  1     Steelhd    Coho       Sockeye
Squw 1   2.906     316.8       6.010     .0000     .9692
         67.81     1167.       78.09     .0000     37.85
         18.43     3230.       41.01     .0000     5.552
         11.49     596.4       13.96     .0000     3.925
         .6090     506.6       6.672     .0000     1.056
     2   .0000   .  0000       .0000     .0000     .0000
         .  0000 .  0000       . 0000    .0000     .0000
         .  0000 .  0000       . 0000    .0000     .0000
                               .0000     0000      .0000
         : 0000 0000 : 0000 0000 .0000   :0000     0000
     3   .0000   .  0000       .0000     .0000     : 0000
```

| | | | | | |
|---|---|---|---|---|---|
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | 0000 | .0000 |
| 4 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| 5 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .1168 | .0000 | .0000 | .0000 | .0000 |
| | .2089E-01 | .0000 | .0000 | .0000 | .0000 |
| | .4021 | .0000 | .0000 | .0000 | .0000 |
| | .7638E-01 | .0000 | .0000 | .0000 | .0000 |
| | .5716 | .0000 | .0000 | .0000 | .0000 |

mort

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | .3761E-02 | .5241E-03 | .8076E-03 | .0000 | .1945E-02 |
| 2 | .8776E-01 | .19313-02 | .1049E-01 | .0000 | .7599E-01 |
| 3 | .2385E-01 | .5344E-02 | .5511E-02 | .0000 | .1114E-01 |
| 4 | .1487E-01 | .9868E-03 | .1875E-02 | .0000 | .78793-02 |
| 5 | .7883E-03 | .83833-03 | .8966E-03 | .0000 | .2120E-02 |
| T | .1310 | .9623E-02 | .1959E-01 | .0000 | .9907E-01 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .1168 | .2089E-01 | .4021 | .7638E-01 | .5716 |

```
  Time    Chin 0 Chin 1 Steelhd Coho    Sockeye Flow    Temp  Efrt12
111.00   .135E+04.198E+05.197E+05.000    .508E+04.580E+0910.6   .000
Gonad inc  .347E-01
```

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | 5.464 | 217.9 | 189.5 | .0000 | 20.96 |
| 2 | 1059. | .7078E+05 | .1737E+05 | .0000 | 1315. |
| 3 | 1276. | .7641E+05 | .2054E+05 | .0000 | 1590. |
| 4 | 368.4 | .9164E+05 | 9673. | .0000 | 556.6 |
| 5 | 62.95 | .3362E+05 | 5147. | .0000 | 293.3 |
| TotPsg | 3332. | .9563E+06 | .7815E+05 | .0000 | 4728. |

Pred Squaws

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | 2791. | .0000 | .0000 | .0000 | .0000 |
| 2 | .6452E+05 | 0000 | .0000 | 0000 | .0000 |
| 3 | 8182. | :0000 | .0000 | :0000 | .0000 |
| 4 | 8182. | .0000 | .0000 | .0000 | .0000 |
| 5 | 899.2 | .0000 | .0000 | 0000 | .0000 |

| Cons | Chin 0 | Chin 1 | Steelhd | Coho' | Sockeye |
|---|---|---|---|---|---|
| Squw 1 | 5.057 | 569.2 | 62.74 | .0000 | 4.229 |
| | 95.83 | 7011. | 482.6 | .0000 | 53.38 |

| | | | | | |
|---|---|---|---|---|---|
| | 105.4 | .2255E+05 | 1205. | .0000 | 47.55 |
| | 36.12 | .1548E+05 | 606.4 | .0000 | 24.71 |
| | 3.518 | 4683. | 226.7 | .0000 | 8.380 |
| 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | 0000 | .0000 | .0000 |
| | .0000 | 0000 | .0000 | .0000 | .0000 |
| 3 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .OOOO | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | 0000 |
| 4 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .000s | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| 5 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | 0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | 0000 | .0000 | 0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .1126 | .0000 | .0000 | .0000 | .0000 |
| | .9746E-01 | .0000 | .0000 | .0000 | .0000 |
| | 2.517 | .0000 | .0000 | .0000 | .0000 |
| | 1.897 | .0000 | 0000 | .0000 | .0000 |
| | 4.898 | .0000 | .0000 | .0000 | .0000 |

| mort | | | | | |
|---|---|---|---|---|---|
| Area 1 | .1518E-02 | .5953E-03 | .8028E-03 | .0000 | .8943E-03 |
| 2 | .2876E-01 | .7332E-02 | .6175E-02 | .0000 | .1129E-01 |
| 3 | .31623-01 | .2358E-01 | .1542E-01 | .0000 | .1006E-01 |
| 4 | .1084E-01 | .1619E-01 | .7759E-02 | .0000 | .5225E-02 |
| 5 | .1056E-02 | .4897E-02 | .2901E-02 | .0000 | .1772E-02 |
| T | .7380E-01 | .5259E-01 | .3306E-01 | .0000 | .2924E-01 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .1126 | .9746E-01 | 2.517 | 1.897 | 4.898 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 121.00 | 624. | .128E+06 | .191E+05 | .000 | .537E+05 | .489E+09 | 10.0 | .000 |

Gonad inc ,138

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | 3.760 | 980.6 | 153.2 | .0000 | 519.4 |
| 2 | 5720. | .1174E+06 | .2877E+05 | .0000 | .5914E+05 |
| 3 | 6317. | .1330E+06 | .3169E+05 | .0000 | .6857E+05 |
| 4 | 2321. | .9673E+05 | .2650E+05 | .0000 | .3462E+05 |
| 5 | 418.1 | .4293E+05 | .1196E+05 | .0000 | .1956E+05 |
| TotPsg | .1988E+05 | .1444E+07 | .2454E+06 | .0000 | .2684E+06 |

Pred Squaws

| | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | 2787. | .0000 | .0000 | .0000 | .0000 |
| | 2 | .6443E+05 | .0000 | .0000 | .0000 | .0000 |
| | 3 | 8173. | .0000 | .0000 | | .0000 |
| | 4 | 8173. | .0000 | .0000 | .0000 | .0000 |
| | 5 | 897.8 | .0000 | .0000 | .0000 | .0000 |

| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| squw | 1 | 18.58 | 1013. | 205.8 | .0000 | 247.6 |
| | | 352.6 | .1164E+05 | 2164. | .0000 | 1355. |
| | | 1184. | .3987E+05 | 7687. | | 5751. |
| | | 331.0 | .3109E+05 | 4513. | .0000 | 2531, |
| | | 29.90 | 7944. | 1281. | .0000 | 645.1 |
| | 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0005 | 0000 | .0000 | .0000 | .0000 |
| | 3 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | 0000 | .0000 | .0000 | | .0000 |
| | 4 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 5 | .0000 | .0000 | .0000 | | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | . | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .3027 | .0000 | .0000 | | .0000 |
| | | .1220 | .0000 | .0000 | .0000 | .0000 |
| | | 3.741 | .0000 | .0000 | | .0000 |
| | | 2.729 | .0000 | .0000 | .0000 | .0000 |
| | | 5.540 | .0000 | .0000 | .0000 | .0000 |

mort

| | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | .9346E-03 | .7019E-03 | .8387E-03 | .0000 | .9225E-03 |
| | 2 | .17743-01 | .8060E-02 | .8821E-02 | .0000 | .5048E-02 |
| | 3 | .5958E-01 | .2762E-01 | .3133E-01 | .0000 | .2143E-01 |
| | 4 | .1665E-01 | .2153E-01 | .1839E-01 | .0000 | .9429E-02 |
| | 5 | .1504E-02 | .5503E-02 | .5221E-02 | .0000 | .2403E-02 |
| | T | .9641E-01 | .6341E-01 | .6460E-01 | .0000 | .3923E-01 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .3027 | .1220 | 3.741 | 2.729 | 5.540 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 131.00 | .495E+04 | .213E+06 | .359E+05 | .000 | .275E+05 | .610E+09 | 11.1 | .000 |

**Gonad inc .138**

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | 16.63 | 1131. | 180.8 | .0000 | 176.9 |
| 2 | 9098. | .2724E+06 | .4235E+05 | .0000 | .7181E+05 |
| 3 | .1030E+05 | .3120E+06 | .4820E+05 | .0000 | .8020E+05 |
| 4 | 4062. | .2264E+06 | .3848E+05 | .0000 | .7293E+05 |
| 5 | 632.4 | .1118E+06 | .1761E+05 | .0000 | .3319E+05 |
| TotPsg | .3587E+05 | .2823E+07 | .4521E+06 | .0000 | .6773E+06 |
| Pred Squaws | | | | | |
| Area 1 | 2783. | 0000 | ..0000 | .0000 | .0000 |
| 2 | .6434E+05 | : 0000 | . 0000 | .0000 | .0000 |
| 3 | 8163. | 0000 | .0000 | .0000 | .0000 |
| 4 | 8163. | : 0000 | .0000 | . 0000 | .0000 |
| 5 | 896.4 | . 0000 | .0000 | . 0000 | 0000 |

| Cons | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| squw 1 | 41.11 | 2958. | 493.9 | .0000 | 827.2 |
| | 771.6 | .2435E+05 | 4365. | .0000 | 6066. |
| | 2162. | .6995E+05 | .1297E+05 | .0000 | .1730E+05 |
| | 884.3 | .6010E+05 | .1051E+05 | .0000 | .1351E+05 |
| | 50.31 | .1124E+05 | 1913. | .0000 | 1964. |
| 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | 0000 | .0000 | .0000 |
| | .0000 | .0000 | : 0000 | .0000 | .0000 |
| | 0 0 0 0 | 0000 | .0000 | .0000 | .0000 |
| | : 0000 | : 0000 | 0000 | .0000 | .0000 |
| 3 | .0000 | 0000 | : 0000 | .0000 | .0000 |
| | .0000 | : 0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | 0000 | .0000 | .0000 |
| | .0000 | .0000 | : 0000 | .0000 | .0000 |
| | .0000 | .0000 | 0000 | .0000 | .0000 |
| 4 | .0000 | .0000 | : 0000 | .0000 | .0000 |
| | .0000 | 0000 | .0000 | .0000 | .0000 |
| | .0000 | : 0000 | .0000 | 0000 | . 0000 |
| | .0000 | 0000 | .0000 | .0000 | .0000 |
| | .0000 | : 0000 | .0000 | .0000 | .0000 |
| 5 | .0000 | 0000 | .0000 | .0000 | .0000 |
| | .0000 | : 0000 | .0000 | 0000 | .0000 |
| | .0000 | .0000 | . 0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | 0000 | . 0000 | .0000 | .0000 |
| | 1.018 | : 0000 | .0000 | 0000 | .0000 |
| | .3114 | .0000 | .0000 | .0000 | .0000 |
| | 5.863 | . 0000 | .0000 | .0000 | .0000 |
| | 5.699 | 0000 | .0000 | .0000 | .0000 |
| | 5.869 | : 0000 | .0000 | .0000 | .0000 |

**mort**

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | .1146E-02 | .10483-02 | .1092E-02 | .0000 | .1221E-02 |
| 2 | .2151E-01 | .8628E-02 | .9656E-02 | .0000 | .8956E-02 |
| 3 | .6028E-01 | .2478E-01 | .2869E-01 | .0000 | .2554E-01 |
| 4 | .2466E-01 | .2129E-01 | .2325E-01 | .0000 | .19953-01 |
| 5 | .1403E-02 | .3981E-02 | .4231E-02 | 0000 | .2900E-02 |

| | | | | | |
|---|---|---|---|---|---|
| T | .1090 | .5973E-01 | .6693E-01 | .0000 | .5856E-01 |

Per capita consumption by area

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | 1.018 | .3114 | 5.863 | 5.649 | 5 5.869 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 141.00 | .764E+04 | .144E+06 | .498E+05 | .000 | .382E+05 | .544E+09 | 13.1 | .000 |

Gonad inc .139

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | 36.44 | 1108. | 292.8 | .0000 | 226.9 |
| 2 | .2183E+05 | .2699E+06 | .5708E+05 | .0000 | .5711E+05 |
| 3 | .2545E+05 | .3026E+06 | .6473E+05 | .0000 | .6360E+05 |
| 4 | 9977. | .2943E+06 | .5575E+05 | . 0000 | .6799E+05 |
| 5 | 1603. | .1215E+06 | .2432E+05 | . 0000 | .2641E+05 |
| TotPsg | .8781E+05 | .4312E+07 | .7524E+06 | .0000 | .9686E+06 |

Pred Squaws

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | 2780. | 0000 | .0000 | . 0000 | .0000 |
| 2 | .6425E+05 | : 0000 | .0000 | .0000 | . 0000 |
| 3 | 8154. | .0000 | 0000 | . 0000 | .0000 |
| 4 | 8154. | . 0000 | : 0000 | .0000 | .0000 |
| 5 | 895.0 | Chin 0000 1 | .0000 | .0000 | .0000 |

| Cons | Chin 0 | | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| squw 1 | 143.8 | 5953. | 1100. | .0000 | 1412. |
| | 2484. | .5437E+05 | 9723. | .0000 | .1273E+05 |
| | 4850. | .1150E+06 | .2110E+05 | .0000 | .2716E+05 |
| | 2048. | .1052E+06 | .1835E+05 | .0000 | .2508E+05 |
| | 97.55 | .1633E+05 | 2800. | .0000 | 3152. |
| 2 | .0000 | 0000 | . 0000 | .0000 | 0000 |
| | . 0000 | : 0000 | .0000 | .0000 | : 0000 |
| | . | 0000 | .0000 | .0000 | .0000 |
| | . 0000 0000 | : 0000 | 0000 | .0000 | 0000 |
| | .0000 | 0000 | : 0000 | .0000 | : 0000 |
| 3 | .0000 | : 0000 | .0000 | .0000 | 0000 |
| | . | .0000 | .0000 | .0000 | : 0000 |
| | . 0000 0000 | . 0000 | .0000 | .0000 | .0000 |
| | : 0000 0000 | 0000 | .0000 | .0000 | 0000 |
| | | : 0000 | .0000 | .0000 | : 0000 |
| 4 | .0000 | .0000 | .0000 | .0000 | 0000 |
| | : 0000 0000 | .0000 | 0000 | .0000 | : 0000 |
| | | . 0000 | : 0000 | .0000 | .0000 |
| | . 0000 | 0000 | .0000 | .0000 | .0000 |
| | 0000 | : 0000 | .0000 | .0000 | 0000 |
| 5 | : 0000 | 0000 | 0000 | .0000 | : 0000 |
| | | : 0000 | : 0000 | .0000 | .0000 |
| | : 0000 0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | . | .0000 | 0000 |
| | . 0000 | .0000 | .0000 | .0000 | : 0000 |
| | 1.542 | .0000 | | .0000 | .0000 |
| | . 6804 | .0000 | | .0000 | .0000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | '8.055 | .0000 | .0000 | .0000 | .0000 |
| | | 8.055 | .0000 | 0000 | .0000 | .0000 |
| | | 8.055 | .0000 | : 0000 | .0000 | .0000 |
| mort | | | | | | |
| Area | 1 | .1637E-02 | .13813-02 | .1462E-02 | .0000 | .1458E-02 |
| | 2 | .2829E-01 | .1261E-01 | .1292E-01 | .0000 | .1314E-01 |
| | 3 | .5523E-01 | .2667E-01 | .2805E-01 | 0000 | .2804E-01 |
| | 4 | .2332E-01 | .2441E-01 | .2439E-01 | : 0000 | .2590E-01 |
| | 5 | .1111E-02 | .3787E-02 | .3722E-02 | .0000 | .3254E-02 |
| | T | .1096 | .6885E-01 | .7054E-01 | . 0000 | .7178E-01 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 1.542 | .6804 | 8.055 | 8.055 | 8.055 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 151.00 | .139E+05 | .264E+05 | .261E+05 | .249E+04 | .327E+05 | .619E+09 | 14.4 | .000 |

Gonad inc .413

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | 72.45 | 392.7 | 448.4 | 14.77 | 367.4 |
| | 2 | .4777E+05 | .1622E+06 | .9622E+05 | 1440. | .8385E+05 |
| | 3 | .5475E+05 | .1760E+06 | .1087E+06 | 1727. | .9391E+05 |
| | 4 | .2124E+05 | .2105E+06 | .8423E+05 | 603.0 | .8110E+05 |
| | 5 | 3467. | .7927E+05 | .3960E+05 | 383.0 | .3580E+05 |
| TotPsg | | .2037E+06 | .5170E+07 | .1262E+07 | 4823. | .1435E+07 |
| Pred Squaws | | | | | | |
| Area | 1 | 2776. | .0000 | .0000 | .0000 | .0000 |
| | 2 | .6416E+05 | .0000 | .0000 | .0000 | .0000 |
| | 3 | 8145. | 0000 | .0000 | .0000 | .0000 |
| | 4 | 8145. | : 0000 | .0000 | .0000 | .0000 |
| | 5 | 893.6 | .0000 | .0000 | .0000 | 0000 |

| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Squw | 1 | 476.2 | 8472. | 2583. | 12.31 | 2771. |
| | | 8823. | .9137E+05 | .2333E+05 | 43.68 | .2603E+05 |
| | | .1554E+05 | .1739E+06 | .4353E+05 | 82.79 | .4885E+05 |
| | | 6491. | .1747E+06 | .3764E+05 | 28.66 | .4570E+05 |
| | | 291.3 | .2377E+05 | 5216. | 4.562 | 5584. |
| | 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | 0000 | 0000 | .0000 | .0000 |
| | | .0000 | : 0000 | : 0000 | 0000 | .0000 |
| | | | .0000 | .0000 | : 0000 | .0000 |
| | | : 0000 0000 | .0000 | .0000 | .0000 | .0000 |
| | 3 | ..0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 0000 | .0000 | .0000 | .0000 | .0000 |
| | | | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | 0000 | 0000 | .0000 | .0000 |
| | | .0000 | : 0000 | : 0000 | [illegible] | .0000 |
| | 4 | .0000 | .0000 | .0000 | [illegible] | .0000 |
| | | .0000 | .0000 | .0000 | [illegible] | .0000 |
| | | .0000 | .0000 | .0000 | [illegible] | .0000 |

| | | | | | |
|---|---|---|---|---|---|
| | .0000 | . 0000 | . 0000 | .0000 | .0000 |
| | .0000 | . 0000 | .0000 | .0000 | 0000 |
| 5 | . 0000 | .0000 | .0000 | .0000 | : 0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 2.054 | . 0000 | .0000 | .0000 | 0000 |
| | 1.095 | .0000 | .0000 | .0000 | : 0000 |
| | 13.97 | . 0000 | .0000 | .0000 | .0000 |
| | 13.97 | .0000 | .0000 . | . 0000 | .0000 |
| | 13.97 | . 0000 | .0000 | .0000 | .0000 |

mort

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | .2337E-02 | .1639E-02 | .2047E-02 | .2551E-02 | .1930E-02 |
| 2 | .4331E-01 | .1767E-01 | .1849E-01 | .9056E-02 | .1814E-01 |
| 3 | .7630E-01 | .3364E-01 | .3450E-01 | .1716E-01 | .3403E-01 |
| 4 | .3186E-01 | .3379E-01 | .2983E-01 | .5942E-02 | .31843-01 |
| 5 | .1430E-02 | .4598E-02 | .4134E-02 | .9459E-03 | .38913-02 |
| T | .1552 | .9133E-01 | .8901E-01 | .3566E-01 | .8983E-01 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 2.054 | 1.095 | 13.97 | 13.97 | 13.97 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrtl2 |
|---|---|---|---|---|---|---|---|---|
| 161.00 | .263E+05 | .974E+04 | .187E+05 | .309E+05 | .194E+05 | .520E+09 | 15.6 | .000 |

Gonad inc .413

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | 81.92 | 91.62 | 95.36 | 113.9 | 236.5 |
| 2 | .6523E+05 | .5598E+05 | .3980E+05 | .1084E+05 | .6683E+05 |
| 3 | .6415E+05 | .5367E+05 | .3921E+05 | .1221E+05 | .6860E+05 |
| 4 | .2793E+05 | .8585E+05 | .4942E+05 | 5 6 6 0 . | . 6538E+05 |
| 5 | 4473. | .2850E+05 | .1878E+05 | 3251. | . 2875E+05 |
| TotPsg | .3269E+06 | .5402E+07 | .1451E+07 | .5116E+05 | .1782E+07 |

Pred Squaws

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | 2772. | .0000 | . 0000 | . 0000 | . 0000 |
| 2 | .6407E+05 | .0000 | . 0000 | 0000 | 0000 |
| 3 | 8135. | .0000 | .0000 | : 0000 | : 0000 |
| 4 | 8135. | 0000 | . 0000 | 0000 | 0000 |
| 5 | 892.2 | : 0000 | . 0000 | : 0000 | : 0000 |

| Cons | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| squw 1 | 766.3 | 8996. | 3010. | 127.2 | 3577. |
| | .1835E+05 | .1081E+06 | .3400E+05 | 765.8 | .3859E+05 |
| | .4266E+05 | .2164E+06 | .7156E+05 | 2433. | .8387E+05 |
| | .1783E+05 | .2348E+06 | .6743E+05 | 1219. | .7830E+05 |
| | 826.7 | .2997E+05 | 8898. | 211.2 | 9814. |
| 2 | .0000 | .0000 | .0000 | 0000 | . 0000 |
| | : 0000 0000 | : 0000 0000 | . .0000 0000 | : 0000 0000 | . . 0000 0000 |
| | . 0000 | . 0000 | . 0000 | : 0000 | . 0000 |

| | | | | | |
|---|---|---|---|---|---|
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| 3 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| 4 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| 5 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .7798 | .0000 | .0000 | .0000 | .0000 |
| | .7828 | .0000 | .0000 | .0000 | .0000 |
| | 16.59 | .0000 | .0000 | .0000 | .0000 |
| | 16.59 | .0000 | .0000 | .0000 | .0000 |
| | 16.63 | .0000 | .0000 | .0000 | .0000 |

mort

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | .2344E-02 | .1665E-02 | .2075E-02 | .2486E-02 | .2008E-02 |
| 2 | .5613E-01 | .2001E-01 | .2344E-01 | .1497E-01 | .2166E-01 |
| 3 | .1305 | .4006E-01 | .4933E-01 | .4757E-01 | .4707E-01 |
| 4 | .5455E-01 | .4346E-01 | .4648E-01 | .2384E-01 | .4395E-01 |
| 5 | .2529E-02 | .5547E-02 | .6134E-02 | .4128E-02 | .5508E-02 |
| T | .2461 | .1107 | .1275 | .92993-01 | .1202 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .7798 | .7828 | 16.59 | 16.59 | 16.63 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 171.00 | .162E+06 | .185E+04 | .292E+04 | 274. | .427E+04 | .497E+09 | 17.3 | .000 |

Gonad inc -.405

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | 595.9 | 10.59 | 25.80 | 2.999 | 45.61 |
| 2 | .5076E+06 | .1217E+05 | .1306E+05 | 6127. | .1731E+05 |
| 3 | .6074E+06 | .1218E+05 | .1375E+05 | 6303. | .1803E+05 |
| 4 | .1663E+06 | .2358E+05 | .1897E+05 | 8352. | .2552E+05 |
| 5 | .3621E+05 | 6873. | 6646. | 3242. | 8717. |
| TotPsg | .1854E+07 | .5442E+07 | .1518E+07 | .1229E+06 | .1857E+07 |

Pred Squaws

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | 2768. | .0000 | .0000 | .0000 | .0000 |
| 2 | .6398E+05 | .0000 | .0000 | .0000 | .0000 |
| 3 | 8126. | .0000 | .0000 | .0000 | .0000 |
| 4 | 8126. | .0000 | .0000 | .0000 | .0000 |
| 5 | 890.8 | .0000 | .0000 | .0000 | .0000 |

| Cons | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| squw | 1 | .1251E+05 | 9157. | 3301. | 343.2 | 3877. |
| | | .8009E+05 | .1137E+06 | .3891E+05 | 3614. | .4573E+05 |
| | | .1320E+06 | .2296E+06 | .8308E+05 | 9926. | .1014E+06 |
| | | .6790E+05 | .2654E+06 | .8778E+05 | 8028. | .1060E+06 |
| | | 4598. | .3342E+05 | .1163E+05 | 1582. | .1379E+05 |
| | 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 3 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 4 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 5 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | 4.590 | .0000 | .0000 | .0000 | .0000 |
| | | 1.285 | .0000 | .0000 | .0000 | .0000 |
| | | 17.10 | .0000 | .0000 | .0000 | .0000 |
| | | 16.67 | .0000 | .0000 | .0000 | .0000 |
| | | 17.16 | .0000 | .0000 | .0000 | .0000 |

mort

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | .6749E-02 | .1683E-02 | .2175E-02 | .2792E-02 | .2088E-02 |
| 2 | .43203-01 | .2089E-01 | .2564E-01 | .2940E-01 | .2463E-01 |
| 3 | .7120E-01 | .4219E-01 | .5475E-01 | .8076E-01 | .5458E-01 |
| 4 | .3663E-01 | .4878E-01 | .5784E-01 | .65323-01 | .5708E-01 |
| 5 | .2480E-02 | .6142E-02 | .7661E-02 | .12883-01 | .7427E-02 |
| T | .1603 | .1197 | .1481 | .1912 | .1458 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 4.590 | 1.285 | 17.10 | 16.67 | 17.16 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 181.00 | .384E+06299. | | 575. | 299. | 500. | .330E+0917.8 | | .000 |

Gonad inc -.316

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | 2407. | 2.067 | 4.109 | 2.067 | 6,873 |
| 2 | .7447E+06 | 2174. | 3095. | 961.5 | 3683. |
| 3 | .1103E+07 | 2637. | 3868. | 1172. | 4565. |
| 4 | .3251E+06 | 5622. | 6013. | 2195. | 7553. |

| | | | | | |
|---|---|---|---|---|---|
| 5 | . 6140E+05 | 1461. | 1897. | 605.2 | 2266. |
| **TotPsg** | .4026E+07 | .5447E+07 | .1532E+07 | .1246E+06 | .1873E+07 |
| **Pred** Squaws | | | | | |
| Area 1 | 2765. | .0000 | .0000 | .0000 | .0000 |
| 2 | .6389E+05 | .0000 | . 0000 | .0000 | . 0000 |
| 3 | 8117. | .0000 | .0000 | .0000 | .0000 |
| 4 | 8117. | .0000 | .0000 | .0000 | .0000 |
| 5 | 889.4 | . 0000 | . 0000 | . 0000 | .0000 |
| Cons | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
| squw 1 | .4074E+05 | 9216. | 3474. | 362.6 | 4048. |
| | .4468E+06 | .1165E+06 | .4240E+05 | 4876. | .5008E+05 |
| | .3113E+06 | .2309E+06 | .8479E+05 | .1055E+05 | .1035E+06 |
| | .2249E+06 | .2734E+06 | .9498E+05 | .1100E+05 | .1155E+06 |
| | .2054E+05 | .3453E+05 | .1283E+05 | 2065. | .1534E+05 |
| 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | . 0005 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | 0000 | .0000 |
| 3 | .0000 | .0000 | .0000 | : 0000 | .0000 |
| | .0000 | . 0000 | .0000 | .0000 | .0000 |
| | 0000 | .0000 | 0000 | .0000 | .0000 |
| | : 0000 | .0000 | : 0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| 4 | .0000 | .0000 | .0000 | .0000 | . 0000 |
| | 0000 | .0000 | 0000 | .0000 | .0000 |
| | : 0000 | .0000 | : 0000 | .0000 | .0000 |
| | 0000 | 0000 | 0000 | 0000 | 0000 |
| | : 0000 | : 0000 | : 0000 | : 0000 | : 0000 |
| 5 | .0000 | .0000 | 0000 | .0000 | .0000 |
| | .0000 | .0000 | :0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | 0000 | .0000 | .0000 |
| | . 0000 | .0000 | : 0000 | .0000 | .0000 |
| | 10.36 | .0000 | .0000 | 0000 | .0000 |
| | 5.923 | .0000 | .0000 | : 0000 | .0000 |
| | 22.80 | .0000 | 0000 | .0000 | .0000 |
| | 22.74 | .0000 | : 0000 | .0000 | .0000 |
| | 22.80 | .0000 | .0000 | .0000 | .0000 |
| mort | | | | | |
| Area 1 | .1012E-01 | .1692E-02 | .2267E-02 | .2910E-02 | .2162E-02 |
| 2 | .1110 | .2139E-01 | .2767E-01 | .3913E-01 | .2674E-01 |
| 3 | .7733E-01 | .4239E-01 | .5533E-01 | .8466E-01 | .5527E-01 |
| 4 | .5587E-01 | .5019E-01 | .61983-01 | .8827E-01 | .6167E-01 |
| 5 | .5102E-02 | .63393-02 | .83763-02 | .1657E-01 | .8193E-02 |
| T | .2594 | .1220 | .1556 | .2315 | .1540 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 10.36 | 5.923 | 22.80 | 22.74 | 22.80 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 191.00 | .216E+06 | 24.5 | 225. | .000 | 199. | .274E+09 | 20.6 | .000 |

Gonad inc -.316

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | 5578. | .8312 | 6.965 | 2.866 | 3.697 |
| | 2 | .7852E+06 | 450.8 | 888.0 | 273.5 | 953.1 |
| | 3 | .1369E+07 | 591.9 | 1179. | 359.9 | 1269. |
| | 4 | .4292E+06 | 1296. | 1764. | 584.3 | 2126. |
| | 5. | 6938E+05 | 315.3 | 513.3 | 157.3 | 600.7 |
| TotPsg | | .6186E+07 | .5449E+07 | .1536E+07 | .1257E+06 | .1877E+07 |

| Pred Squaws | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | 2761. | .0000 | .0000 | .0000 | .0000 |
| | 2 | .6380E+05 | .0000 | .0000 | .0000 | .0000 |
| | 3 | 8108. | 0000 | 0000 | .0000 | .0000 |
| | 4 | 8108. | 0000 | 0000 | .0000 | .0000 |
| | 5 | 888.0 | .0000 | .0000 | .0000 | .0000 |

| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| squw | 1 | .8416E+05 | 9239. | 3547. | 385.0 | 4128. |
| | | .9979E+06 | .1173E+06 | .4360E+05 | 5251. | .5152E+05 |
| | | .5366E+06 | .2312E+06 | .8517E+05 | .1067E+05 | .1040E+06 |
| | | .4447E+06 | .2751E+06 | .9693E+05 | .1168E+05 | .1179E+06 |
| | | .4420E+05 | .3478E+05 | .1319E+05 | 2179. | 1577E+05 |
| | 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | 0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | 0000 | 0000 | .0000 | .0000 | .0000 |
| | 3 | .0000 | .0000 | .0000 | .0000 | 0000 |
| | | 0000 | 0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | 0000 | .0000 | .0000 | .0000 | 0000 |
| | | .0000 | 0000 | 0000 | .0000 | .0000 |
| | 4 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | 0000 | 0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | 0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 5 | 0000 | 0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | 0000 | .0000 | .0000 |
| | | .0000 | 0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | 0000 | 0000 | .0000 | .0000 |
| | | 15.79 | .0000 | .0000 | .0000 | .0000 |
| | | 8.692 | .0000 | .0000 | .0000 | .0000 |
| | | 27.92 | .0000 | .0000 | .0000 | .0000 |
| | | 27.92 | .0000 | .oobo | .0000 | .0000 |
| | | 27.92 | .0000 | .0000 | .0000 | .0000 |

| mort | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | .1360E-01 | .16963-02 | .2309E-02 | .3062E-02 | .2199E-02 |
| | 2 | .1613 | .2153E-01 | .2838E-01 | .4176E-01 | .2745E-01 |
| | 3 | .8674E-01 | .4243E-01 | .5544E-01 | .8484E-01 | .5538E-01 |

| | | | | | |
|---|---|---|---|---|---|
| 4 | .7188E-01 | .5049E-01 | .6309E-01 | .9292E-01 | .6282E-01 |
| 5 | .7145E-02 | .6384E-02 | .8585E-02 | .1733E-01 | .8402E-02 |
| T | .3407 | .1225 | .1578 | .2399 | .1562 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 15.79 | 8.692 | 27.92 | 27.92 | 27.92 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 201.00 | .226E+06 | .000 | 374. | .000 | 75.2 | .271E+09 | 21.4 | .000 |

Gonad inc .339E-01

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | 4688. | 1.713 | 5.567 | .4283 | 5.139 |
| | 2 | .9534E+06 | 116.3 | 411.9 | 72.38 | 363.9 |
| | 3 | .2082E+07 | 174.3 | 606.7 | 111.9 | 550.6 |
| | 4 | .6420E+06 | 309.0 | 615.4 | 166.7 | 686.9 |
| | 5 | .1020E+06 | 74.41 | 206.2 | 48.01 | 207.5 |
| TotPsg | | 9859E+07 | .5449E+07 | .1538E+07 | .1260E+06 | .1879E+07 |

Pred Squaws

| | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | 2757. | .0000 | .0000 | .0000 | .0000 |
| | 2 | .6371E+05 | 0000 | .0000 | .0000 | .0000 |
| | 3 | 8099. | .0000 | .0000 | .0000 | .0000 |
| | 4 | 8099. | .0000 | .0000 | .0000 | .0000 |
| | 5 | 886.6 | .0000 | .0000 | .0000 | .0000 |

| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Squw | 1 | .1767E+06 | 9250. | 3601. | 392.3 | 4180. |
| | | .1999E+07 | .1175E+06 | .4413E+05 | 5394. | .5213E+05 |
| | | .8215E+06 | .2312E+06 | .8529E+05 | .1070E+05 | .1041E+06 |
| | | .7281E+06 | .2755E+06 | .9750E+05 | .1186E+05 | .1186E+06 |
| | | .7509E+05 | .3484E+05 | .1330E+05 | 2212. | .1591E+05 |
| | 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | 0000 | 0000 | .0000 | .0000 |
| | | | .0000 | .0000 | .0000 | .0000 |
| | 3 | 0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | 0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | 0000 | 0000 | .0000 | .0000 | .0000 |
| | 4 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 5 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | | .0000 | .0000 | .0000 | .0000 |

| | | | | | |
|---|---|---|---|---|---|
| | 33.59 | 0000 | 0000 | .0000 | .0000 |
| | 15.73 | : 0000 | : 0000 | .0000 | .0000 |
| | 35.21 | . 0000 | .0000 | .0000 | 0000 |
| | 35.21 | .0000 | .0000 | .0000 | : 0000 |
| | 35.21 | .0000 | .0000 | .0000 | .0000 |

mort

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | .1792E-01 | .16983-02 | .2341E-02 | .3113E-02 | .2224E-02 |
| 2 | .2028 | .2157E-01 | .2869E-01 | .4280E-01 | .2774E-01 |
| 3 | .8333E-01 | .4243E-01 | .5545E-01 | .8490E-01 | .55403-01 |
| 4 | .7385E-01 | .5055E-01 | .6339E-01 | .9414E-01 | .6312E-01 |
| 5 | .7617E-02 | .6394E-02 | .8649E-02 | .17553-01 | .8464E-02 |
| T | .3855 | .1226 | .1585 | .2425 | .1569 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 33.59 | 15.73 | 35.21 | 35.21 | 35.21 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 211.00 | .317E+05 | .000 | 75.2 | ,000 | .000 | .213E+09 | 23.3 | .000 |

Gonad inc .339E-01

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | 317.6 | 0000 | 1.082 | .0000 | .5223 |
| 2. | 6397E+06 | 24.70 | 178.9 | 15.24 | 107.5 |
| 3. | 1593E+07 | 32.98 | 240.3 | 20.64 | 145.1 |
| 4. | 6551E+06 | 85.49 | 321.5 | 49.42 | 253.5 |
| 5 | .8343E+05 | 19.10 | 102.9 | 11.61 | 69.69 |
| TotPsg | 1113E+08 | .5449E+07 | .1539E+07 | .1261E+06 | .1880E+07 |

Pred Squaws

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | 2753. . | 0000 | 0000 | .0000 | . 0000 |
| 2 | 6362E+05 | 0000 | : 0000 | .0000 | 0000 |
| 3 | 8090. . | 0000 | . 0000 | .0000 | : 0000 |
| 4 | 8090. | 0000 | 0000 | .0000 | . 0000 |
| 5 | 885.2 : | 0000 | : 0000 | 0000 | .0000 |

| Cons | Chin 0 | Chin 1 | Steelhd | Coho' | Sockeye |
|---|---|---|---|---|---|
| squw 1 | .2144E+06 | 9251. | 3633. | 393.0 | 4192. |
| | .2619E+07 | .1176E+06 | .4437E+05 | 5421. | .5229E+05 |
| | .1043E+07 | .2312E+06 | .8534E+05 | .1071E+05 | .1041E+06 |
| | .9496E+06 | .2755E+06 | .9766E+05 | .1190E+05 | .1188E+06 |
| | .9928E+05 | .3485E+05 | .1335E+05 | 2219. | .1594E+05 |
| 2 | .0000 | 0000 | .0000 | . 0000 | . 0000 |
| | . 0000 : | 0000 | : 0000 | .0000 | : 0000 |
| | . 0000 . | 0000 | 0000 | .0000 | 0000 |
| | . 0000 : | 0000 | : 0000 | .0000 | : 0000 |
| | 0000 | 0000 | 0000 | 0000 | 0000 |
| 3 | :0000 | .0000 | 0000 | : 0000 | . 0000 |
| | .0000 . | 0000 | : 0000 | .0000 | . 0000 |
| | .0000 . | 0000 | .0000 | .0000 | .0000 |
| | .0000 . | 0000 | .0000 | .0000 | 0000 |
| | 0000 . | 0000 | .0000 | 0000 | : 0000 |
| 4 | :0000 | .0000 | .0000 | : 0000 | . 0000 |

| | | | | | |
|---|---|---|---|---|---|
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| 5 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 13.69 | 0000 | .0000 | .0000 | .0000 |
| | 9.738 | .0000 | .0000 | .0000 | .0000 |
| | 27.41 | .0000 | .0000 | 0000 | .0000 |
| | 27.41 | .0000 | .0000 | .0000 | 0000 |
| | 27.41 | .0000 | .0000 | .0000 | .0000 |

| mort | | | | | |
|---|---|---|---|---|---|
| Area 1 | .19263-01 | .1698E-02 | .2360E-02 | .3118E-02 | .2230E-02 |
| 2 | .2352 | .2157E-01 | .2882E-01 | .4301E-01 | .2782E-01 |
| 3 | .9370E-01 | .4243E-01 | .5544E-01 | .8493E-01 | .5540E-01 |
| 4 | .8529E-01 | .5056E-01 | .6344E-01 | .9438E-01 | .63183-01 |
| 5 | .8917E-02 | .6396E-02 | .8670E-02 | .1760E-01 | .8479E-02 |
| T | .4424 | .1227 | .1587 | .2430 | .1571 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 13.69 | 9.738 | 27.41 | 27.41 | 27.41 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 221.00 | .372E+04 | .000 | 75.2 | .000 | .000 | .239E+09 | 22.2 | .000 |

Gonad inc .200E-02

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | 127.1 | .0000 | 1.417 | .0000 | .4614 |
| | 2 | .3621E+06 | 5.206 | 194.1 | 10.97 | 79.28 |
| | 3 | .8353E+06 | 5.798 | 231.7 | 12.73 | 94.20 |
| | 4 | .4311E+06 | 18.29 | 190.5 | 19.34 | 95.50 |
| | 5 | .4496E+05 | 3.742 | 82.62 | 6.261 | 35.57 |
| TotPsg | | .1126E+08 | .5449E+07 | .1540E+07 | .1261E+06 | .1880E+07 |

| Pred | Squaws | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | 2750. | .0000 | .0000 | .0000 | .0000 |
| | 2 | .6353E+05 | .0000 | .0000 | 0000 | .0000 |
| | 3 | 8081. | .0000 | .0000 | .0000 | .0000 |
| | 4 | 8081. | .0000 | .0000 | 0000 | .0000 |
| | 5 | 883.9 | .0000 | .0000 | .0000 | .0000 |

| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| squw | 1 | .2161E+06 | 9251. | 3648. | 394.1 | 4197. |
| | | .2845E+07 | .1176E+06 | .4445E+05 | 5430. | .5232E+05 |
| | | .1312E+07 | .2312E+06 | .8539E+05 | .1071E+05 | .1042E+06 |
| | | .1218E+07 | .2755E+06 | .9777E+05 | .1191E+05 | .1188E+06 |
| | | .1286E+06 | .3486E+05 | .1338E+05 | 2223. | .1596E+05 |
| | 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |

| | | | | | |
|---|---|---|---|---|---|
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| 3 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | 0000 | .0000 |
| | .0000 | .0000 | .0000 | : 0000 | .0000 |
| | . 0000 | .0000 | .0000 | .0000 | .0000 |
| 4 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | . 0000 | .0000 | .0000 | .0000 | .0000 |
| | . 0000 | .0000 | .0000 | .0000 | .0000 |
| 5 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | . 0000 | .0000 | .0000 | 0000 | .0000 |
| | .0000 | .0000 | .0000 | : 0000 | .0000 |
| | 3.569 6387 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 |
| | 33.19 | 0000 | .0000 | 0000 | .0000 |
| | 33.19 | : 0000 | .0000 | : 0000 | .0000 |
| | 33.19 | .0000 | .0000 | .0000 | .0000 |

mort

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | .1920E-01 | .1698E-02 | .2368E-02 | .3125E-02 | .2233E-02 |
| 2 | .2527 | .2157E-01 | .2885E-01 | .4305E-01 | .2783E-01 |
| 3 | .1165 | .4243E-01 | .55443-01 | .8491E-01 | .5540E-01 |
| 4 | .1081 | .5057E-01 | .6348E-01 | .9444E-01 | .6321E-01 |
| 5 | 1142E-01 | .6397E-02 | .8689E-02 | .1763E-01 | .8488E-02 |
| T | : 5079 | .1227 | .1588 | .2432 | .1572 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .6387 | 3.569 | 33.19 | 33.19 | 33.19 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 231.00 | .777E+04 | .000 | 50.7 | .000 | .000 | .222E+09 | 21.1 | .000 |

Gonad inc .200E-02

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | 163.5 | 0000 | 1.037 | .0000 | . 0000 |
| 2 | .2208E+06 | : 9472 | 145.7 | 12.39 | 44.77 |
| 3 | . 3362E+06 | .8482 | 152.4 | 12.56 | 45.14 |
| 4 | . 1685E+06 | 2.381 | 107.9 | 10.16 | 40.20 |
| 5 | . 1945E+05 | .5391 | 55.70 | 5.267 | 18.99 |
| TotPsg | .1134E+08 | .5449E+07 | .1541E+07 | .1262E+06 | .1880E+07 |

Pred Squaws

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | 2746. | . 0000 | . 0000 | .0000 | .0000 |
| 2 | .6344E+05 | 0000 | . 0000 | 0000 | .0000 |
| 3 | 8071. | : 0000 | 0000 | : 0000 | . 0000 |
| 4 | 8071. | . 0000 | : 0000 | 0000 | .0000 |
| 5 | 882.6 | . 0000 | . 0000 | : 0000 | . 0000 |

| cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| squw | 1 | .2176E+06 | 9251. | 3663. | 395.5 | 4202. |
| | | .2945E+07 | .1176E+06 | .4450E+05 | 5435. | .5234E+05 |
| | | .1598E+07 | .2312E+06 | .8548E+05 | .1072E+05 | .1042E+06 |
| | | .1499E+07 | .2755E+06 | .9791E+05 | .1193E+05 | .1189E+06 |
| | | .1593E+06 | .3486E+05 | .1345E+05 | 2229. | .1598E+05 |
| | 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 3 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 4 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 5 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .5592 | .0000 | .0000 | .0000 | .0000 |
| | | 1.566 | .0000 | .0000 | .0000 | .0000 |
| | | 35.50 | .0000 | .0000 | .0000 | .0000 |
| | | 34.90 | .0000 | .0000 | .0000 | .0000 |
| | | 34.95 | .0000 | .0000 | .0000 | .0000 |

| mort | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | .1919E-01 | .1698E-02 | .2377E-02 | .3134E-02 | .2235E-02 |
| | 2 | .2596 | .2157E-01 | .2887E-01 | .4306E-01 | .2784E-01 |
| | 3 | .1409 | .4243E-01 | .5547E-01 | .8493E-01 | .5542E-01 |
| | 4 | .1322 | .5057E-01 | .6353E-01 | .9449E-01 | .6323E-01 |
| | 5 | .1405E-01 | .6397E-02 | .8726E-02 | .1766E-01 | .8501E-02 |
| | T | .5659 | .1227 | .1590 | .2433 | .1572 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .5592 | 1.566 | 35.50 | 34.90 | 34.95 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 241.00 | .340E+04 | .000 | .000 | .000 | .000 | .215E+09 | 20.6 | .000 |

Gonad inc .200E-02

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | 193.7 | .0000 | 1.572 | .0000 | .0000 |
| | 2 | .1258E+06 | .1229 | 77.31 | 1.187 | 18.84 |
| | 3 | .9262E+05 | .8754E-01 | 80.04 | .8223 | 15.66 |
| | 4 | .7426E+05 | .3362 | 56.69 | 2.223 | 21.97 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 8059. | .7154E-01 | 24.45 | .6007 | 8.816 |
| **TotPsg** | | .1141E+08 | .5449E+07 | .1541E+07 | .1262E+06 | .1880E+07 |
| Pred Squaws | | | | | | |
| Area | 1 | 2742. | .0000 | .0000 | .0000 | .0000 |
| | 2 | .6335E+05 | .0000 | .0000 | .0000 | .-0000 |
| | 3 | 8060. | .0000 | .0000 | 0000 | .0000 |
| | 4 | 8060. | .0000 | .0000 | : 0000 | 0000 |
| | 5 | 881.3 | .0000 | .0000 | .0000 | : 0000 |

| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| squw | 1 | .2191E+06 | 9251. | 3669. | 395.5 | 4206. |
| | | .3003E+07 | .1176E+06 | .4453E+05 | 5436. | .5236E+05 |
| | | .1804E+07 | .2312E+06 | .8557E+05 | .1072E+05 | .1042E+06 |
| | | .1609E+07 | .2755E+06 | .9799E+05 | .1193E+05 | .1189E+06 |
| | | .1734E+06 | .3486E+05 | .1349E+05 | 2232. | .1600E+05 |
| | 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | .0000 | .0000 | .0000 | .0000 | .0000 |
| | 3 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | | | .0000 | .0000 | .0000 | .0000 |
| | | : 0000 0000 | .0000 | [illegible] | .0000 | .0000 |
| | | .0000 | .0000 | [illegible] | .0000 | .0000 |
| | | . . 0000 | .0000 | [illegible] | .0000 | .0000 |
| | 4 | .0000 | .0000 | [illegible] | .0000 | .0000 |
| | | .0000 | 0000 | [illegible] | .0000 | .0000 |
| | | .0000 | : 0000 | [illegible] | .0000 | .0000 |
| | | : 0000 0000 | .0000 | [illegible] | .0000 | .0000 |
| | | | .0000 | [illegible] | .0000 | .0000 |
| | 5 | .0000 | 0000 | [illegible] | .0000 | .0000 |
| | | .0000 | : 0000 | [illegible] | .0000 | .0000 |
| | | | 0000 | [illegible] | .0000 | .0000 |
| | | : 0000 0000 | : 0000 | [illegible] | .0000 | .0000 |
| | | .5285 0000 | 0000 | [illegible] | .0000 | .0000 |
| | | | : 0000 | [illegible] | .0000 | .0000 |
| | | .9177 | .0000 | [illegible] | .0000 | .0000 |
| | | 25.53 | 0000 | [illegible] | 0000 | 0000 |
| | | 13.63 | : 0000 | [illegible] | : 0000 | : 0000 |
| | | 16.02 | .0000 | [illegible] | .0000 | .0000 |

| mort | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | .1920E-01 | .1698E-02 | .2380E-02 | .3134E-02 | .2237E-02 |
| | 2 | .2631 | .2157E-01 | .2889E-01 | .4307E-01 | .27843-01 |
| | 3 | .1581 | .4243E-01 | .5551E-01 | .8496E-01 | .5543E-01 |
| | 4 | .1410 | .5057E-01 | .6357E-01 | .9453E-01 | .63243-01 |
| | 5 | .1520E-01 | .63973-02 | .8748E-02 | .1768E-01 | .8508E-02 |
| | T | .5966 | .1227 | .1591 | .2434 | .1573 |

Per capita consumption by area

| **Area** | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .5285 | .9177 | 25.53 -- | 13.63 | 16.02 |

Elapsed time: 245.460600 seconds

Appendix D-3

# Columbia River Ecosystem Model
## Version 2.05

Program listing, input data and example output

Incorporating

- dynamic fishing mortality
- movement among reservoir areas by predators
- stochastic variability in parameters and driving functions
- complex reservoir area structure and salmonid migration route
- bio-energetics and related population dynamics for predators

```
      program crem205
c Ver 2.05, 12/15/89:
c++   --1.1, 1.3 Fishery mortality-- Effort & catchabilities
c++   --1.2 Equilibrium densities by area, migration coefficients
c++   --1.4, 1.5 Expand number of fish species/size categories, add PS
c           for predator weights, add energetics eqn. for growth, add
c           reproduction, add population structure & juvenile predator
c++   --1.7 Option for stochastic variation of params & forcing functi
c++   --1.8 Save final PSV's for re-initialisation,
c     --1.9 (not here)
c++   --1.10 Add loop for manual param modification
C Ver 1.3, 3/24/89:
c     -- Modification to provide for stochastic functional response
c        to prey density-- substitute function stosig for sigmo in
c        subroutine isv
c     -- Add printout of position on functional response curve--
c        "predator efficiency"
c Ver 1.2, 2/6/89:
c     --Modification to allow repeated simulations with one parameter
c       read from file 'times.dat', intended to perform stochastic
c       simulation of residence time, output on unit 3, mortality
c       of juv sp. 1 in area 2 (sub-yearling chin in reservoir)
c Ver 1.1, 6/21/88:
c     --Juveniles defined as numbers in area, convert to density
c        for functional response (modified der)
c     --Modify functional response to include temp effect & sigmoid
c       curve
c     --Change to Mm^3/da units for passage file, convert MI to passag
c       numbers with Vigg regression
c     --Add velocity threshold for predation
c     --Add spawning effect on functional response
c     --Add cumulative mortality calculation and printout
c Columbia River Ecosystem Model, Predation, Ver 1.0
c Incorporates Ver 0.9 to allow input of predator numbers by
c type, area and month for check of consumption against time invariant
c model-- File name 'pdfil' contains name of file with time series
c of predator numbers by type and area
c Note subscript order conventions for psv's as follows:
c Juveniles: Jv(species,area)
c Predators: Pn(species,area)
c Consumption rate: Cn(juv. sp.,area,pred. sp.)
c Per capita consumption: Cp(pred. sp.,area)
      real vp(261)
      logical debug, deriv
$INCLUDE: 'cremfil.cmn'
      real sav(261)
      character*72 runame
$INCLUDE: 'Crem20.cmn'
      tim(ih,im,is,id)=(ihr*3600+im*60+is)+id/100.
      call getdat(iyr,imon,iday)
      call gettim(ihr,imin,isec,idum)
      et=tim(ihr,imin,isec,idum)
```

```
      open(5,FILE='simpar.dat')
c      open(3,FILE='crem.out')
      read(5,1100)runame
      read(5,100)ne,np,nisv,na,njv,npd,nsg,npg,
     >debug,deriv,t1,t2,tp,dtt
      read(5,*)nrpt,nyr
      write(*,200)iyr,imon,iday,ihr,imin,isec
      write(*,1100)runame
      write(*,1100)
      write(*,300)ne,np,nisv,na,njv,npd,nsg,npg,
     >debug,deriv,t1,t2,tp,dtt
      if(nrpt.ne.1)write(*,*)'Repeated simulation,',nrpt,' times'
      if(nyr.ne.1)write(*,*)'Multi-year simulation,',nyr,' years'
c      read(5,800)n1,(n2(i),i=1,n1)
c      write(*,900)n1,(n2(i),i=1,n1)
c      write(3,1000)iyr,imon,iday,ihr,imin,isec,n1,(n2(i),i=1,n1)
      read(5,700)dfil,tfil,ffil,pfil,gfil,pdfil
      write(*,*)'Data file names: '
      write(*,*)dfil,tfil,ffil,pfil,gfil,pdfil
c Initialise arrays to zero
      call init(vp,ne,0.)
      call init(psv,ne+1,0.)
c Read initial conditions
      call inicon(nic)
      write(*,*)'Initial conditions read,',nic,' values'
c Open file with residence times if repeated simulation
      if(nrpt.ne.1) open(9,file='times.dat')
c     write(*,500)(psv(i),i=32,56)
c     read(5,400) (F(i),i=2,8)
      close (5)
c     write(*,*)' Loc 5, debug,dtt ',debug,dtt
      call input(debug,deriv,tl)
c Save initial conditions in order to restart simulation
      call copy(psv,sav,ne)
c     write(*,*)' Loc 6, debug,dtt ',debug,dtt
      if(nrpt.eq.1)write(*,600)
c Iterate on number of repeated simulations
      do 10 i=1,nrpt
      call copy(sav,psv,ne)
      if(nrpt.ne.1) read(9,*)ii,prt1(1,2)
c Iterate annual loop
      do 20 j=1,nyr
      if(nyr.gt.1) write(*,*)'          Year ',j,' simulation'
      t=t1-tp
1     t=t+tp
      call output(t, j,vp,debug,deriv)
      if(t*1.00001.ge.t2) go to 20
      call integ(t,t+tp,vp,dtt)
      go to 1
20    call grad(tl,j)
10    continue
      call gettim (ihr,imin,isec,idum)
```

```
      et=tim(ihr,imin,isec,idum)-et
      write(*,*),Elapsed time =',et,' seconds,
      close (3)
100   format(8i5,2l2,4f5.0)
200   format(////10x,'*****************************************'/10x,
     + '*  Columbia River Predation Simulator *'/10x,
     + '*             Ver. 2.05               *'/10x,
     + '*     Stochastic Functional Response  *'/10x,
     + '*     Fishing Effort and Mortality    *'/10x,
     + '*     Inter-area Predator Migration   *'/10x,
     + '*     Energetics & Age Structure      *'/10x,
     + '*   '6i5,4x,'*'/10x,
     + '*****************************************'//)
300    format(5x,' No. of equations = ',i3,', No. of parameters = ',
     +  i5/5x,' No. of isv''s = ',i3,', No. of areas = ',i3/5x,
     + ' No. of prey types = 'i3,', No. of pred. types = ',
     +  i3/5x,' No. juv. pred. ages = ',i3,', No. adult pred. ages = ,
     +  i3/5x,' Debug output? ',l2,', Derivative output? ',l2/5x,
     + ' Start time = ',f10.5,', End time = ',f10.5/5x,
     + , Print interval = ',f10.5,', Integration step size = ',f10.5//
     +)
600   format(/10x,' Time, Driving variables,'/18x,'PSV''s'/)
400   format(10e6.0)
500   format(5g12.4)
700   format(6a12)
800   format(21i3)
900   format(5x,i5,' psv''s for CREM.OUT: '20i3)
1000  format('CREM 1.1 '6i5/21i3)
1100  format(a72)
      end
c--------------------------------------------
      subroutine inicon(ii)
$INCLUDE: 'crem20.cmn'
      character*10 nmp
C Reads initial condition values for psv's
    read(5,*)
      ii=0
1     ii=i+1
      read(5,100)i,j,k,l,nmp,p
      go to (11,12,13,14,15,16,17,18) i
11    Jv(j,k)=p
      go to 99
12    Pn(j,k)=p
      go to 99
13    Cn(j,k,l)=p  .
      go to 99
14    Cp(j ,k)=p
      go to 99
15    Pw(j ,k)=p
      go to 99
16    Sn(j)=p
      go to 99
```

```
17    Sw(j)=p
      go to 99
18    Eg=p
99    if(.not.eof(5)) go to 1
      close(5)
100   format(4i5,5x,a10,e10.4)
      return
      end
C-----------------------------------------------
      subroutine input(debug,deriv,t1)
      character*10 nmp
      character*34 des
      logical debug,deriv,ageflg
      real d2(15)
      common/stopred/nfq,pdrate(10),freq(10)
$INCLUDE: 'cremfil.cmn'
$INCLUDE: 'Crem20.cmn'
      data ageflg/.false./
      call init(par,np,0.)
      call init(isv,nisv,0.)
      call init(nj,25,0.)
      open(2,FILE=dfil)
c read area adjacency matrix, nj
      read(2,*)
      read(2,1200) nj
      write(*,1300) nj
      read(2,*)
      read(2,*)
      write(*,400)
      ii=0
1     ii=ii+1
      read(2,100)i,j,k,l,nmp,p,des
      write(*,200)ii,i,nmp,j,k,l,p,des
c read parameters
      go to (21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,
     >39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56) i
21    pa(j)=p
      go to 99
22    pg(l)=p
      go to 99
23    prt1(j,k)=p
      go to 99
24    prt2(j,k)=p
      go to 99
25    prc1(l)=p
      go to 99
26    prc2(l)=p
      go to 99
27    prc3(l)=p
      go to 99
28    prc4(l)=p
      go to 99
```

```
29    prc5(l)=p
      go to 99
30    prc6(l)=p
      go to 99
31    pmt(l)=p
      go to 99
32    pvt=p
      go to 99
33    psp1(l)=p
      go to 99
34    psp2(l)=p
      go to 99
35    psp3(l)=p
      go to 99
36    psf(l)=p
      go to 99
37    psd=p
      go to 99
38    pq(l)=p
      go to 99
39    pPn(k,l)=p
      go to 99
40    pmg(l)=p
      go to 99
41    pae=p
      go to 99
42    pw1=p
      go to 99
43    pw2=p
      go to 99
44    pqw(j)=p
      go to 99
45    pms(j)=p
      go to 99
46    pme=p
      go to 99
47    pli=p
      go to 99
48    pbk=p
      go to 99
49    pt0=p
      go to 99
50    pwl=p
      go to 99
51    plt=p
      go to 99
52    pnw=p
      go to 99
53    pww=p
      go to 99
54    prf=p
      go to 99
```

```
55    pwj=p
      go-to 99
56    psl=p
99    if(.not.eof(2)) go to 1
      close(2)
      write(*,500)ii
      open(4,FILE=tfil)
c     read(4,300)
2     read(4,300)i,tday(i),temp(i)
c     write(*,300)i,tday(i),temp(i)
      if(.not.eof(4)) go to 2
     _ntemp=i
      close(4)
      write(*,600)ntemp
      open(4,FILE=ffil)
c     read(4,300)
3     read(4,300)i,fday(i),flow(i)
c convert flow from Mm^3/da to m^3/da
      flow(i)=flow(i)*1.E6
      if(.not.eof(4)) go to 3
      nflow=i
      close(4)
      write(*,700)nflow
C Read passage file (pfil)
      open(4,FILE=pfil)
c     read(4,300)
4     read(4,300)i,jday(i),(juv(j,i),j=1,njv)
C Convert migration index to passage numbers
      do 110 j=1,njv
110   juv(j,i)=juv(j,i)*1.748
      if(.not.eof(4)) go to 4
      njp=i
      close(4)
      write(*,800)njp
C Read gonad file (gfil)
      open(4,FILE=gfil)
c     write(*,*)' npd= ',npd
      if(npd.eq.1.and.npg.gt.1)ageflg=.true.
6     read(4,300)i,gday(i),(gonad(j,i),j=1,npd)
      if(ageflg) then
            do 170 j=2,npg
170         gonad(j,i)=gonad(1,i)
      endif
c     write(*,*)i,gday(i),(j,gonad(j,i),j=l,npd)
      if(.not.eof(4)) go to 6
      ngon=i
      close(4)
      write(*,1000)ngon
c read predator effort file by type and area, if present
      pdday(1)=-1.
      if(pdfil.ne.'              ')then
        open(4,FILE=pdfil)
```

```
        i=0
5       i=i+1
            read(4,900)pdday(i),((predef(j,k,i),j=1,5),k=1,5)
c           write(*,*)pdday(i),((predef(j,k,i),j=1,5),k=1,5)
            if(.not.eof(4)) go to 5
        npdf=i
        close(4)
        write(*,1100)npdf
      endif
c set up stochastic predation empirical distribution
      nfq=psf(3)
      do 120 i=l,nfq
            j=2*i+2
            pdrate(i)=psf(j)
120         freq(i)=psf(j+l)
c initialize ran & constants
      g1=pli*pwl**.333333
      g3=3.*pbk
      dl=ran(psd)
c distribute catchability coefficients & mortality if not defined in i
c --assume all ages equally catchable
      if(pq(1) .gt.0..and.pq(2).le.0.) then
            call init(pq,npg,pq(1) )
            write(*,*)'Parameters pq(2-5) set to pq(l) ,',pq(1)
      endif
      if(pmt(1).gt.0..and.pmt(2).le.0.) then
            call init(pmt,npg,pmt(1))
            write(*,*) 'Parameters pmt(2-5) set to pmt(1),',pmt(1)
      endif
      if(prc6(2).le.0.) then
            call init(prc1,npg,prc1(1))
            call init(prc2,npg,prc2(1))
            call init(prc3,npg,prc3(1))
            call init(prc4,npg,prc4(1))
            call init(prc5,npg,prc5(1))
            call init(prc6,npg,prc6(1))
            write(*,*)'Parameters prci(2-5) set to prci(1)'
      endif
      if(psp2(2).le.0.) then
            call init(psp1,npg,psp1(1))
            call init(psp2,npg,psp2(1))
            call init(psp3,npg,psp3(1))
            write(*,*)'Parameters pspi(2-5) set to pspi(1)'
      endif
      if(pmg(2).le.0.) then
            call init(pmg,npg,pmg(1))
            write(*,*)'Parameters pmg(2-5) set to pmg(1)'
      endif
c initialize predator age structure
      if((npd.eq.l).and.(npg.gt.l))  then
            npd=npg
c distribute adult predators across areas, everything in age 1 initial
```

```
c --assume a single total population number has been initialised
            tot=Pn(1,1)
            do 130 i=1,na
130         Pn(1,i)=pPn(1,i)*tot
      else
            tot=sum22(Pn,1,na)
      endif
c calc age distribution based on mortalities
c --pmt is inst. daily mort during growing season
c --pnw is total over-wintering mortality
c --psl is season length, days
      dl=l.-pnw
      s=l.
      d2(1)=1.
      d4=t1/365.+nsg
      do 140 i=2,npg
            d2(i)=d2(i-1)*d1*exp(-pmt(i)*psl)
140         s=s+d2(i)
c distribute adult predators across ages and areas
      do 150 i=npg,1,-1
            d3=d2(i)/s
            age=d4+i
            do 150 j=1,na
                  Pn(i,j)=d3*Pn(1,j)
                  Pw(i,j)=wlgth(vbg(age))
150               pPn(i,j)=d3*pPn(1,j)
c calculate juvenile predator age structure & weights
c --pms() is annual total mortalitv for iuveniles, assumed to over-win
      Sn(nsg)=sum22(Pn,1,npg)/(1.-pms(nsg))
      age=d4
      Sw(nsg)=wlgth(vbg(age))
      do 160 i=nsg-1,1,-1
            age=age-1.
            Sn(i)=Sn(i+1)/(1.-pms(i))
160         Sw(i)=wlgth(vbg(age))
      Eg=Sn(1)/(1.-pme)
100   format(4i5,5x,a10,e10.4,a34)
200   format(1x,2i5,1x,a10,'(',3i2,') =',g18.6,1x,a34)
300   format(i5,f5.0,6f10.2)
400   format(/2x,'Recd Blk Param        Ndx           Value'
     >'         Description'/1x,78('-'))
500   format(/' Parameter input complete',i5,' recds')
600   format(' Temperature input complete',i5,' recds')
700   format(' Flow input complete',i5,' recds')
800   format(' Passage input complete',i5,' recds')
900   format(f5.0/(10e5.0))
1000  format(' Gonad increment input complete',i5,' recds')
1100  format{' Predator effort input complete',i5,' recds')
1200  format(5f2.0)
1300  format(/' Area adjacency matrix'/(1x5f5.2))
      return
      end
```

```
c-----------------------------------------------
      subroutine output(t,jyr,vp,debug,deriv)
$INCLUDE: 'cremfil.cmn'
      real vp(261),d1(5,5),d3(5)
      logical debug,deriv
$INCLUDE: 'Crem20.cmn'
      data d1/25*0./
      yr=jyr-1
      if(nrpt.eq.1) then
      call force(t)
      write(*,100)t,(F(i),i=2,8),ef(1,2),(Fg(i),i=1,npd)
      write(*,200)(psv(i),i=2,181)
C Calculate total mortalities and print (Jv(i,6) has cum passage)
      do 10 i=1,njv
      d3(i)=0.
      do 10 j=1,na
      if (Jv(i,6).ne.0.) d1(i,j)=sum33(Cn,i,j,npd)/Jv(i,6)
10    d3(i)=d3(i)+d1(i,j)
      write(*,500)(j,(d1(i,j),i=1,5),j=1,na)
      write(*,600)'T',d3
      write(*,700)(j,j=1,na),(i,(Cp(i,j),j=1,na) ,i=1,npd)
      write(*,800)(j,j=1,na),(i,(flwght(Pw(i,j)),j=1,na),i=l,npd)
      write(*,900)Eg,Sn,(flwght(Sw(i)),i=1,15)
      call init(Cp,25,0.)
c      write(3,150)t,(psv(n2( i)),i=1,n1)
c      write(3,150)t,(Jv(i,6),i=1,njv),((d1(i,j),i=1,njv),j=1,na)
c      write(3,150)t,Fs,Fl,Ft,Fg(1),((d1(i,j),i=1,njv),j=1,na),g2
c     write(*,*)' Loc 1',deriv,debug
      if(deriv) then
c     write(*,*)' Loc 2'
      call der(t,vp)
      write(*,300)
      write(*,200) (vp(i),i=1,ne)
      endif
      if(debug) then
      write(*,400) (isv(i),i=2,nisv+1)
      endif
c     write(*,*)' Loc 3'
100   format(/'   Time    Chin 0 Chin 1  Steelhd  Coho    '
     >'Sockeye Flow    Temp Efrt12'/1x,f6.2,4x,8g8.3/
     >1x,'Gonad inc '5g9.3/)
200   format(/' Prey Chin 0      Chin 1      Steelhd      '
     >'Coho         Sockeye'/' Area 1',5g12.4/6x'2',5g12.4/6x'3',5g12.4
     >6x,'4',5g12.4/6x,'5',5g12.4/' TotPsg'5g12.4/
     >' Pred Squaws'/' Area 1',5g12.4/
     >6x,'2',5g12.4/6x,'3',5g12.4/6x,'4',5g12.4/6x,'5',5g12.4/
     >' Cons  Chin 0      Chin 1      Steelhd     Coho       Sockeye'/
     >' squw 1',5g12.4/4(7x,5g12.4/),6x'2'5g12.4/4(7x,5g12.4/),6x'3'
     >5g12.4/4(7x,5g12.4/),6x'4'5g12.4/4(7x,5g12.4/),6x'5'5g12.4
     >/(7x,5g12.4))
150    format(21e12.4)
300   format(1x,'Derivatives')
```

```
400   format(1x,'Intermediate System Variables'/(7x,5g12.4))
500   format(' mort '/' Area',i2,5g12.4/(5x,i2,5g12.4))
600   format(6x,a1,5g12.4)
700   format(/' Per capita consumption by area'/' Area'2x,i7,4i12/
     >'    Pred'i2,5g12.4/(5xi2,5g12.4))
800   format(/' Predator lengths by area'/' Area'2x,i7,4i12/
     >' Pred'i2,5g12.4/(5xi2,5g12.4))
900   format(/' Eggs produced = ',g12.4/
     >' Juvenile predators:'/3(7x,5g12.4/)/
     >' Juvenile predator lengths:'/3(7x5g12.4/))
      return
      endif
      write(*,*)t,prt1(1,2),sum33(Cn,1,2,npd)/Jv(1,6)
      return
      end
c-----------------------------------------------
      subroutine integ(t1,t2,vp,dtt)
      dimension vp(261)
$include: 'Crem20.cmn'
c     write(*,*)' integ: t1,t2,dtt ',t1,t2,dtt
      n=(t2-t1)/dtt+.001
      t=t1-dtt
      do 20 i=1,n
      t=t+dtt
      call der(t,vp)
      do 20 j=1,ne
      psv(j+l)=psv(j+l)+vp(j)*dtt
      if (psv(j+1).le. l-e-10) psv(j+l)=0.0
c       write(*,*)'Neg psv at time ',t,', psv(',j,')=',psv(j+1)
20    continue
      return
      end
c-----------------------------------------------
      subroutine der(t,vp)
      real vp(261),d4(5,5),d5(5,5)
SINCLUDE: 'Crem20.cmn'
c functions to calculate equivalent linear subscripts for
c 2 & 3 dimensioned arrays-- these work only for dimensions
c of (5,5) and (5,5,5) and must be modified if array
c dimensions are changed
      ij(i,j)=(j-1)*5+i
      ijk(i,j,k)=ij(i,j)+(k-1)*25
c     write(*,*)' Loc 21'
c Find driving function values
      call force(t)
c     write(*,*)' Loc 22'
c update juvenile squaw weights using VB growth-- not integrated
      do 70 i=1,nsg
      age=i+t/365.
70    Sw(i)=wlgth(vbg(age))
c Find intermediate variable values
      call isvt(t)
```

```
c Calculate derivatives
c     write(*,100)t
100   format(' Derivatives being calculated at t ='
     >,f10.4)
c Prey migration and consumption
      do 10 i=1,njv
C Calc deriv's of Jv, area 1:
      vp(ij(i,1))=Fs(i)-Jv(i,1)/rt(i,1)-sum33(rc,i,1,npd)
      do 10 j=2,na
c Sum contributions from other areas according to
c proportions in adjacency matrix, nj
      d3=0.
      do 50 k=1,na
50    if((nj(j,k).gt.0.).and.(nj(j,k).le.1.)) d3=d3+
     >nj(j,k)*Jv(i,k)/rt(i,k)
C Calc deriv's of Jv, areas 2 - na:
10    vp(ij(i,j))=d3-Jv(i,j)/rt(i,j)-sum33(rc,i,j,npd)
c Predator mortality and consumption audit,
c Von Bertanffy consumption and difference from actual
      S=0 .
      do 20 i=1,npd
      do 20 j=1,na
c calc net migration
      d3=0.
      do 40 k=l,na
40    d3=d3+mg(j,k,i)*Pn(i,k)
C Calc deriv's of Pn:
      vp(ij (i,j)+30)=-(pmt(i)+pq(i)*ef(i,j))*Pn(i,j)+d3
C Calc total consumption (d4) and positive diff from VB consumption (d
C s is food available for egg production, pwj converts numbers to gram
      d4(i,j)=sum31(rc,i,j,njv)*pwj
      d5(i,j)=max(0.,d4(i,j)-vc(i,j))
      s=s+d5(i,j)
      do 20 k=1,njv
c     write(*,400)i,j,k,ijk(i,j,k)
C Calc deriv's of Cn:
20    vp(ijk(k,j,i)+55)=rc(k,j,i)
C Calc deriv's of Sn
* (In-season mortality zero for this version)
*     do 80 i=1,15
*     if(i.le.nsg) then
*           vp(i+230)=alog(1.-pms(i))*Sn(i)/365.
*     else
*           vp(i+230)=0.
*80     endif
C Calc deriv of Eg, egg production rate
      vp(261)=s/prf
C Calc deriv's of cum passage in Jv(i,6):
      do 30 k=1,njv
30    vp(ij (k, 6) )=Fs(k)
cCalc per capita consumption & weight deriv's
      do 60 i=1,npd
```

```
      do 60 j=l,na
C Calc deriv's of Pw:
      vp(ij(i,j)+205)=pae*d4(i,j)-pw1*qw*Pw(i,j)**pw2-d5(i,j)
C Calc consumption deriv's
60    vp(ij(i,j)+180)=sum31(rc,j,i,njv)/Pn(i,j)
c     write(*,300)(psv(i),i=2,ne+1)
c     write(*,200)(vp(i),i=1,ne)
c300   format(' Der-- psv''s'/(5g12.4))
c200   format(' Der-- dpsv''s'/(5g12.4))
400   format('  Der-- indices'/5i5)
      return
      end
c--------------------------------------------------
      subroutine force(t)
c Find instantaneous forcing function values from
c incremental time series
$INCLUDE: 'Crem20.cmn'
      data i1/2/,i2/2/,i3/2/,i4/1/,i5/2/,j/1/
c     write(*,100)t
100   format(' Forcing functions being calculated at t ='
     >,f10.4)
c Reinitialise for new year
      if(t.lt.tday(j)) then
              i1=2
              i2=2
              i3=2
              i4=1
              i5=2
      endif
C temperature
c assumes that flow rate is characteristic of midday (hence, t-.5)
      do 10 i=i1,ntemp
      if (tday(i).ge.t) go to 1
10    continue
      i=ntemp
1     j=i-1
      i1=max(i-2,2)
      Ft=xlin(temp(j),temp(i),tday(j),tday(i),t-.5)
c Flow rate
c assumes that flow rate is characteristic of midday (hence, t-.5)
      do 20 i=i2,nflow
      if (fday(i).ge.t) go to 2
20    continue
      i=nflow
2     j=i-1
      i2=max(i-2,2)
      Fl=xlin(flow(j),flow(i),fday(j),fday(i),t-.5)
c Juvenile passage rates
      do 30 i=i3,njp
      if (jday(i).ge.ifix(t+1.0001)) go to 3
30    continue
      i=njp
```

```
3      j=i
       i3=max(i-2,2)
       do 40 k=1,njv
40     Fs(k)=juv(k,j)
c Gonad sizes
       do 60 i=i5,ngon
       if (gday(i).ge.t) go to 4
60     continue
       i=ngon
4      j=i-1
       i5=max(i-2,2)
       do 70 k=1,npd
70     Fg(k)=xlin(gonad(k,j),gonad(k,i),gday(j),gday(i),t)
c Setup effort levels if data present (pdday(1).ne.-1.)
       if(t.eq.pdday(i4)) then
       do 50 i=1,5
       do 50 j=1,5
50     ef(i,j)=predef(i,j,i4)
       i4=i4+1
       endif
       return
       end
c-----------------------------------------------------------
       subroutine isvt(t)
$INCLUDE: 'Crem20.cmn'
c      write(*,100)t
100    format(' ISVs being calculated at t ='
      >,f10.4)
c Temperature effect on respiration
       qw=gg(-Ft,0.,-pqw(1),pqw(2),pqw(3))
c Residence times
       do 10 i=1,njv
       do 10 j=1,na
       rt(i,j)=prt1(i,j)+prt2(i,j)*pa(j)/Fl
       if (rt(i,j).le.0.) then
          write(*,*) 'rt:',i,j,rt
       endif
10     continue
C Total prey densities by area
       do 30 j=1,na
       tJv(j)=0.
       do 40 i=1,njv
40     tJv(j)=tJv(j)+Jv(i,j)
30     tJv(j)=tJv(j)/pa(j)
C Consumption rates
c      if(t.ge.96.55)write(*,*)'t=',t
       do 90 k=1,npd
C ct calculates temperature effect on functional response
       ct=prc1(k)*gg(Ft,0.,prc4(k),prc5(k),prc6(k))
C sp is spawning effect on functional response
       sp=psp1(k)+(1.-psp1(k))*at(Fg(k),psp2(k),psp3(k))
c      if(t.ge.96.55)write(*,*)' k=',k,', ct=',ct,', sp=',sp
```

```
      do 20 j=na,1,-1
C calc Von Bertalanffy consumption (vc == ge*)
      vc(k,j)=gestar(Pw(k,j))
C ePn is 'effective predator density' due to water velocity threshold,
      ePn=swtch(Pn(k,j),0.,pvt-Fl/pa(j))
      g2=sigmo(tJv(j),prc2(k),prc3(k))
      if (psf(2).le.0.) then
          d1=ct*g2*ePn*sp
      else
          d1=ct*stosig(g2,tJv(j),psf)*ePn*sp
      endif
c     if(t.ge.96.55)write(*,*)'j=',j,', ePn=',ePn,', d1=',d1
      do 20 i=1,njv
C rc is temp effect X func. resp.(total prey) X ePn X prop. of prey sp
      if (tJv(j).gt.0.) then
         rc(i,j,k)=d1*Jv(i,j)/(pa(j)*tJv(j))
      else
         rc(i,j,k)=0.
      endif
c     if (t.ge.96.55)write(*,*)'i=',i,', rc=',rc(i,j,k),Jv(i,j),pa(j)
20    continue
c migration rates, adjacency matrix designates non-zero migration isv'
c sum predators
      tPn=sum22(Pn,k,na)
      do 70 j=1,na
      do 70 i=1,na
      if (nj(i,j).gt.0) then
        d3=pmg(k)/(sqrt(pa(i))+sqrt(pa(j)))
        mg(j,i,k)=d3*swtch(1.,0.,pPn(k,j)-(Pn(k,j)/tPn))
70    endif
c calc diagonal term to ensure conservation
      do 50 i=1,na
      d3=0.
      do 60 j=1,na
60    if (i.ne.j) d3=d3+mg(j,i,k)
50    mg(i,i,k)=-d3
90    continue
c10    write(*,200)i,j,k,rc(i,j,k)
c200   format(' isv, (i,j,k) = '3i2', rc = 'g12.4)
      return
      end
C-----------------------------------------
      subroutine grad(t1,jyr)
C graduate the cohorts annually
$INCLUDE: 'crem20.cmn'
      logical gflg
      real adist(5)
      gflg=.true.
      npg1=npg-1
      do 10 i=1,na
c graduate the predator classes, oldest first, accumulating in class n
      tot=Pn(npg,i)+Pn(npgl,i)
```

```
      s=o.
      do 10 i=1,na
      pop(i)=sum21(Pn,i,npg)
10    s=s+pop(i)
      do 20 i=l,na
20    ad(i)=pop(i)/s
      return
      end
C-----------------------------------------
      real function flwght(w)
$INCLUDE: 'crem20.cmn'
C calc fork length for a given weight
      flwght=0.
      if(w.le.0.)return
      flwght=(w/pwl)**.3333333
      return
      end
C-----------------------------------------
      real function wlgth(xl)
$INCLUDE: 'crem20.cmn'
C calc weight for a given fork length
      wlgth=pwl*xl**3
      return
      end
C-----------------------------------------
      real function vbg(age)
$INCLUDE: 'crem20.cmn'
C calc Von Bertalanfy fork length for a given age
      vbg=pli*(1.-exp(-pbk*(age-pt0)))
      return
      end
C-----------------------------------------
      real function gestar(w)
C calc Von Bertalanffy consumption rate
$INCLUDE: 'crem20.cmn'
      gestar=0.
      if(w.le.0.)return
      gestar=(g3*g1*W**.666667-g3*w+pw1*w**pw2)/pae
      return
      end
C-----------------------------------------
      real function arr(T, P1,P2)
      arr= (10**(p1*T+p2))*.69315
      return
      end
C-----------------------------------------
      real function swtch(x,y,z)
      swtch=x
      if (z.le.0.) swtch=y
      return
      end
C-----------------------------------------
```

```
      Pw(npg,i)=((Pw(npg,i)*Pn(npg,i)+Pw(npg1,i)*Pn(npg1,i))/tot)*pww
      Pn(npg,i)=tot*pnw
c graduate the younger predator classes
      do 20 j=npg1,2,-1
      j1=j-1
      Pn(j,i)=Pn(j1,i)*pnw
20    Pw(j,i)=Pw(j1,i)*pww
      Pn(1,i)=0.
10    Pw(1,i)=0.
c graduate the juvenile squaws
1     if(flwght(Sw(nsg)).gt.plt)  then
c juvenile becomes predator class
c first find area distribution of predators, distribute juveniles
accordingly
            if(gflg) call dist(adist,gflg)
            Sn(nsg)=Sn(nsg)*pnw
            Sw(nsg)=Sw(nsg)*pww
            do 30 i=1,na
            Pn(1,i)=Sn(nsg)*adist(i)+Pn(1,i)
30          Pw(1,i)=(Sw(nsg)*Sn(nsg)+Pw(1,i)*Pn(1,i))/(Sn(nsg)+Pn(1,i)
            Sn(nsg)=0.
            nsg=nsg-1
            if(nsg.lt.1) call error('grad',1)
c check to see if new biggest juvenile is large enough for predator cl
            go to 1
      else
c graduate the remaining squaw juveniles, Eggs go to class 1
            do 40 j=nsg,1,-1
            j1=j+1
            Sn(j1)=Sn(j)*(1.-pms(j))
40          Sw(j1)=Sw(j)*pww
            nsg=nsg+1
            if(nsg.gt.15) call error('grad',2)
            Sn(1)=Eg*pme
            Eg=0.
            Sw(1)=wlgth(vbg(1.+t1/365.))
      endif
      if(gflg) then
            write(*,*)'No juvenile predators graduated this year'
      endif
      write(*,*)'Year:',jyr,'; No. juvenile cohorts:',nsg,
     >'; Area1 dist. of predators:'
      write(*,*)adist
      return
      end
C-----------------------------------------
      subroutine dist(ad,flg)
c Calculate area1 distribution of predators
$INCLUDE: 'crem20.cmn'
      real ad(5),pop(5)
      logical flg
      flg=.false.
```

```
      real function xlin(y1,y2,x1,x2,x)
      xlin=y1+(y2-y1)*((x-x1)/(x2-x1))
      return
      end
c----------------------------------------------
      subroutine  init(x,n,p)
      real x(1)
      do 10 i=1,n
10    x(i)=p
      return
      end
c----------------------------------------------
      subroutine ninit(m,n,j)
      integer m(1)
      do 10 i=1,n
10    m(i)=j
      return
      end
c----------------------------------------------
      real function sum21(x,i,n)
c Sums a doubly subscripted array, x, over n values
c the first index, for i the second index
      real x(5,5)
      s=0.
      do 10 k=l,n
10    s=s+x(k,i)
      sum21=s
      return
      end
c----------------------------------------------
      real function sum22(x,i,n)
c Sums a doubly subscripted array, x, over n values
c the second index, for i the first index
      real x(5,5)
      s=0.
      do 10 k=l,n
10    s=s+x(i,k)
      sum22=s
      return
      end
c----------------------------------------------
      real function sum33(x,i,j,n)
c Sums a triply subscripted array, x, over n values of
c the third index, for i,j the first & second indices
      real x(5,5,5)
      sum=0.
      do 10 k=1,n
10    sum=sum+x(i,j,k)
      sum33=sum
      return
      end
c----------------------------------------------
```

```
      real function sum31(x,j,k,n)
c sums a triply subscripted array, x, over n values of
c the first index, for j,k the second & third indices
      real x(5,5,5)
      sum=o.
      do 10 i=1,n
10    sum=sum+x(i,j,k)
      sum31=sum
      return
      end
c-----------------------------------------------
      real function gg(x,a,b,c,d)
c Generalised Gamma function
      x1=(x-a)/(b-a)
      gg=x1**c*exp((c/d)*(1.-x1**d))
      return
      end
c-----------------------------------------------
      real function sigmo(x,a,b)
C Sigmoid function, asymptote is 1.0
c Artificially force through (0.,0.)
c Stretch to range (0.,1.) [No-- commented out]
      sigmo=0.
      if(x.le.0.) return
c      c=l./a
      sigmo=l./(l.+a*exp(-b*x))
c      sigmo=(l.+c)*sigmo-c
      return
      end
c-----------------------------------------------
      subroutine copy(x,y,n)
      real x(1) ,y(1)
      do 10 i=1,n
10    y(i)=x(i)
      return
      end
c-----------------------------------------------
      real function stosig(xmu,x,ps)
c Generates stochastic functional response curve
      dimension ps(1)
      common/stopred/nfq,pdrate(10),freq(10)
      if (x.gt.ps(1)) then
          d1=xmu+gauss(0.,ps(2))
          stosig=d1
          return
      else
          d1=emp(pdrate,freq,nfq)
      endif
      stosig=dl
      return
      end
c-----------------------------------------------
```

```
      real function gauss(xmu,sd)
1     x1=ran(0.)
      x2=ran(0.)
      c1=sin(6.283185*x1)*sqrt(-2.*alog(x2))
      gauss=c1*sd+xmu
      return
      end
c-----------------------------------------------------
      real*4 function ran(x)
c Pseudo-random number generator, mid-square method,
c double precision generation, single precision result
c repeat interval 2 - 5e5, depending on seed!
      real*8 y
      if(x.ne.0.) then
        seed-x
        y-x
      ran=y
        return.
      endif
      y=y*seed*1.e5
      y=y-float(ifix(y))
      ran=y
      return
      end
c-----------------------------------------------------
      real function emp(x,y,n)
c Generates random number from empirical distribution
c given by x,y histogram with n-l bars, assumes
C sigma(y)=1.0, n>1, x strictly monotonic increasing
      dimension x(1),y(1)
      z=ran(0.)
      sum=o.
      do 10 i=2,n
      sum=sum+y(i)
      if (z.le.sum) go to 1
10    continue
      i=n
1     ii=i-1
      emp=x(ii)+ran(0.)*(x(i)-x(ii))
      return
      end
C-----------------------------------------------------
```

```
      subroutine error(msg,ndx)
      character*8 msg
      write (*,*)'Error halt from ',msg,', index= ',ndx
      stop
      end
C-----------------------------------------------------
      real function at(x,p1,p2)
      parameter (pi=3.14159)
      TK=tan(.4*pi)/(p2)
      at=1./pi*atan(TK*(x-p1))+.5
      if (at.lt. 0.) at=0.
      return
      end
C--------------------------------------------
```

Common'file crem20.cmn:

```
      common/drvr/F(1),Fs(5),Fl,Ft,Fg(5)
*     Jv(sp,area)    Pn(sp,area)    Cn(Juv sp,area,Prd sp)
      common/psv/psv(1),Jv(5,6),Pn(5,5),Cn(5,5,5),Cp(5,5),Pw(5,5),
     >Sn(15),Sw(15),Eg
      real Jv
      common/isv/isv(1),rt(5,5),rc(5,5,5),tJv(5),ef(5,5),
     >ct,ePn,sp,tPn,mg(5,5,5),vc(5,5),qw
      real isv,mg
      common/par/par(1),pa(5),pg(5),prt1(5,5),prt2(5,5),prc1(5),
     >prc2(5),prc3(5),prc4(5),prc5(5),prc6(5),pmt(5),pvt,
     >psp1(5),psp2(5),psp3(5),psf(15),psd,pq(5),pPn(5,5),pmq(5),
     >pae,pw1,pw2,pqw(3),pms(15),pme,pli,pbk,pt0,pwl,plt,pnw,pww,
     >prf,pwj,psl
      common/ndx/ne,np,nisv,na,njv,npd,nrpt,nyr,npg,nsg,g1,g2,g3,
     >nj(5,5)
      real nj
      common/drvrfil/ntemp,tday(200),temp(200),nflow,fday(200),
     >flow(200),njp,jday(200),juv(5,200),pdday(6),predef(5,5,6),
     >ngon,gday(20),gonad(5,20)
      real jday,juv
```

Common file cremfil.cmn:

```
      common/fname/dfil,tfil,ffil,pfil,pdfil,gfil,n1,n2(20)
      character*12 dfil,tfil,ffil,pfil,pdfil,gfil
```

Input data file crem.dat:

Adjacency matrix:
```
.o-4.5.1.0
0.0..2.2.6
0..20..2.6
0..2.20..6
0.0.0.0.0.
```

Parameter values

| No. | 1st | 2nd | 3rd | ---- | Name | | Value | Description |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | | | | pa 1 m2 | | .46E6 | Area |
| 1 | 2 | | | | pa 2, m2 | | 166.E6 | " |
| 1 | 3 | | | | pa 3, m2 | | 21.E6 | " |
| 1 | 4 | | | | pa 4, m2 | | 21.E6 | " |
| 1 | 5 | | | | pa 5, m2 | | 2.336 | " |
| 2 | | | 1 | | pg 1 | | .228 | (not used) |
| 4 | 1 | 1 | | | prt2 1 1 | | 10. | Residence time, flow pro |
| 4 | 2 | 1 | | | prt2 2 1 | | 10. | |
| 4 | 3 | 1 | | | prt2 3 1 | | 10. | |
| 4 | 4 | 1 | | | prt2 4 1 | | 10. | |
| 4 | 5 | 1 | | | prt2 5 1 | | 10. | |
| 3 | 1 | 2 | | | prtl 1 2 | | 18.9 | Residence time, absolute days |
| 3 | 2 | 2 | | | prtl 2 2 | | 3.6 | |
| 3 | 3 | 2 | | | prtl 3 2 | | 3.6 | |
| 3 | 4 | 2 | | | prtl 4 2 | | 3.6 | |
| 3 | 5 | 2 | | | prtl 5 2 | | 3.6 | |
| 3 | 1 | 3 | | | prtl 1 3 | | 18.9 | |
| 3 | 2 | 3 | | | prtl2 3 | | 3.6 | |
| 3 | 3 | 3 | | | prtl 3 3 | | 3.6 | |
| 3 | 4 | 3 | | | prtl 4 3 | | 3.6 | |
| 3 | 5 | 3 | | | prtl 5 3 | | 3.6 | |
| 3 | 1 | 4 | | | prtl 1 4 | | 37.8 | |
| 3 | 2 | 4 | | | prtl 2 4 | | 7.2 | |
| 3 | 3 | 4 | | | prtl 3 4 | | 7.2 | |
| 3 | 4 | 4 | | | prtl 4 4 | | 7.2 | |
| 3 | 5 | 4 | | | prtl 5 4 | | 7.2 | |
| 3 | 1 | 5 | | | prtl 1 5 | | 1. | |
| 3 | 2 | 5 | | | prtl 2 5 | | 1. | |
| 3 | 3 | 5 | | | prtl 3 5 | | 1. | |
| 3 | 4 | 5 | | | prtl 4 5 | | 1. | |
| 3 | 5 | 5 | | | prtl 5 5 | | 1. | |
| 5 | | | 1 | | prcl | 1 | 5.048 | Max temp effect on consumption |
| 6 | | | 1 | | prc2 | 1 | 82.626 | 1/1+prc2 = int. of Func. Resp. |
| 7 | | | 1 | | prc3 | 1 | 774.14 | rate param of Func. Resp |
| 8 | | | 1 | | prc4 | 1 | 21.5 | Temp. at max cons. rate |
| 9 | | | 1 | | prc5 | 1 | 3.4 | shape param for temp eff |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10 | | | 1 | prc6 | | 1 | 13.8 | shape param for temp eff |
| 11 | | | 1 | pmt | | 1 | 0. | daily inst. mort. for Sq |
| 12 | | | | pvt | | | 8.6434 | Velocity threshold for feeding |
| 13 | | | 1 | psp1 | | 1 | .2 | Params- spawning effect->feeding |
| 14 | | | 1 | psp2 | | 1 | -.5 | " |
| 15 | | | 1 | psp3 | | 1 | 1. | " |
| 16 | | | 1 | psf | | 1 | .0035 | Params and breakpoints f |
| 16 | | | 2 | psf | | 2 | .00 | (.11) empirical distribu |
| 16 | | | 3 | psf | | 3 | 4. | function for stochasti |
| 16 | | | 4 | psf | | 4 | 0. | functional response cu |
| 16 | | | 5 | ps f | | 5 | ,267 | |
| 16 | | | 6 | psf | | 6 | .015 | |
| 16 | | | 7 | psf | | 7 | ,267 | |
| 16 | | | 8 | psf | | 8 | ,105 | |
| 16 | | | 9 | psf | | 9 | ,433 | |
| 16 | | | 10 | psf | | 10 | .165 | |
| 16 | | | 11 | psf | | 11 | ,233 | |
| 16 | | | 12 | psf | | 12 | .230 | |
| 16 | | | 13 | psf | | 13 | .067 | V |
| 17 | | | | psd | | | .43215 | Seed for random no. gene |
| 18 | | | 1 | pq | | 1 | .293e-3 | Catchability coefficient |
| 19 | | 1 | 1 | pPn | 1 | 1 | .03300 | Distribution of adult predators |
| 19 | | 1 | 2 | pPn | 1 | 2 | .76300 | across areas, sums to |
| 19 | | 1 | 3 | pPn | 1 | 3 | .09700 | |
| 19 | | 1 | 4 | pPn | 1 | 4 | .09700 | |
| 19 | | 1 | 5 | pPn | 1 | 5 | .01000 | V |
| 20 | | | 1 | pmg | 1 | | .05 | Migr. rate const., 1/(da |
| 21 | | | | pae | | | .4 | Assimilation efficiency |
| 22 | | | | pw1 | | | .01 | Respiration coeff. at op temp |
| 23 | | | | pw2 | | | .66 | Respiration exponent |
| 24 | 1 | | | pqw | 1 | | 21.5 | Temp at max respiration |
| 24 | 2 | | | pqw | 2 | | 1. | Shape param for resp-tern |
| 24 | 3 | | | pqw | 3 | | 1. | Shape param for resp-tern |
| 25 | 1 | | | pms | 1 | | .9 | Juv. squaw mort., 1/yr, |
| 25 | 2 | | | pms | 2 | | .75 | annual total |
| 25 | 3 | | | pms | 3 | | .6 | |
| 25 | 4 | | | pms | 4 | | .5 | |
| 25 | 5 | | | pms | 5 | | .4 | |
| 25 | 6 | | | pms | 6 | | .1 | |
| 25 | 7 | | | pms | 7 | | .05 | |
| 25 | 8 | | | pms | 8 | | .01 | |
| 25 | 9 | | | pms | 9 | | .01 | |
| 25 | 10 | | | pms | 10 | | .01 | |
| 26 | | | | pme | | | .99 | Egg to age 1 mort., 1/yr |
| 27 | | | | pli | | | 520. | Loo |
| 28 | | | | pbk | | | .162 | Brody growth coef., k |
| 29 | | | | pt0 | | | .018 | to of VB growth |
| 30 | | | | pwl | | | 1.56E-5 | wt-lngth conv, g/mm3 |

```
   31                   plt            400.  length threshold for pre
mm
   32                   pnw              .6 Over-winter  survival
   33                   pww             .90 Over-winter weight facto
   34                   prf              .5 g of food/egg
   35                   pwj             2.0 av. wt. of juv. salmonid
   36                   psl            153.  Season-length, days
```

Input data file for simulation parameters simpar.dat:

```
 Five areas, migration, no fishing, ge & energetics w/ juv. Squaws
  261  193  335    5    5    1    9    5 F F  91, 101.   1.  .01
 1 1
crem.dat    temp85.dat  flow85.dat  pass85.dat  gonad.dat   effrt.dat
No. | 1st| 2nd| 3rd|----| Name     | Value   | Description

    2    1    1          Pn           85316. Predator numbers, Total
```

Output file (standard output -- executed on NEC Prospeed 386 without coprocessor):

```
***************************************
*  Columbia River Predation Simulator *
*            Ver. 2.05                *
*     Stochastic Functional Response  *
*     Fishing Effort and Mortality    *
*     Inter-area Predator Migration   *
*     Energetics & Age Structure      *
*    1990    7   24  13    3   34     *
***************************************
```

Five areas, migration, no fishing, ge & energetics w/ juv. Squaws

```
     No. of equations = 261, No. of parameters =   193
     No. of isv's = 335, No. of areas = 5
     No. of prey types =   5, No. of pred. types =   1
     No. juv. pred. ages =   9, No. adult pred. ages = 5
     Debug output?  F, Derivative output? F
     Start time =   91.00000, End time =  101.00000
     Print interval =    1.00000, Integration step size =     .01000
```

Data file names:

```
crem.dat    temp85.dat  flow85.dat pass85.dat gonad.dat   effrt.dat
Initial conditions read,          1 values
```

Area adjacency matrix

```
   :00 00   .40 00   .50 .20   .10 .20   .60 .00
            ...
   . 00     .20      .00      .20      .60
   .00      .20      .20      .00      .60
   .00      .00      .00      .00      .00
```

```
 Recd Blk Param        Ndx            Value       Description
-------------------------------------------------------------------------B-m-
    l    1 pa 1  m2   ( 10 0) =      460000.       Area
    2    1 pa 2, m2   ( 2 0 0) =     .166000E+09   "
    3    1 pa 3, m2   (3 0 0) =      .210000E+08   "
    4    1 pa 4, m2   (4 0 0) =      .210000E+08   "
    5    1 pa 5, m2   ( 5 0 0) =     .230000E+07   "
    6    2 pg 1       ( 0 0 1) =     .228000       (not used)
    7    4 prt2 1 1   ( 1 1 0) =     10.0000       Residence time, flo
prop.
    8    4 prt2 2 1   ( 2 1 0) =     10.0000
    9    4 prt2 3 1   ( 3 1 0) =     10.0000
   10    4 prt2 4 1   ( 4 1 0) =     10.0000
   11    4 prt2 5 1   ( 5 1 0) =     10.0000
```

```
  12    3 prtl 1 2   ( 1 2 0) =      18.9000      Residence time,
absolute, days
  13    3 prt1 2 2   ( 2 2 0) =      3.60000
  14    3 prtl 3 2   ( 3 2 0) =      3.60000
  15    3 prtl 4 2   ( 4 2 0) =      3.60000
  16    3 prtl5 2    ( 5 2 0) =      3.60000
  17    3 prt1 1 3   ( 1 3 0) =      18.9000
  18    3 prtl 2 3   ( 2 3 0) =      3.60000
  19    3 prtl 3 3   ( 3 3 0) =      3.60000
  20    3 prt1 4 3   ( 4 3 0) =      3.60000
  21    3 prt1 5 3   ( 5 3 0) =      3.60000
  22    3 prt114     ( 14 0) =       37.8000
  23    3 prt12 4    ( 2 4 0) =      7.20000
  24    3 prtl 3 4   ( 3 4 0) =      7.20000
  25    3 prt1 4 4   ( 4 4 0) =      7.20000
  26    3 prt1 5 4   ( 5 4 0) =      7.20000
  27    3 prtl 1 5   ( 1 5 0) =      1.00000
  28    3 prt1 2 5   ( 2 5 0) =      1.00000
  29    3 prtl 3 5   ( 3 5 0) =      1.00000
  30    3 prtl 4 5   ( 4 5 0) =      1.00000
  31    3 prtl 5 5   ( 5 5 0) =      1.00000
  32    5 prcl      1( 0 0 1) =      5.04800      Max temp effect on
consumption
  33    6 prc2      1( 0 0 1) =      82.6260      1/1+prc2 = int. of
Resp.
  34    7 prc3      1( 0 0 1) =      774.140      rate param of Func.
Resp.
  35    8 prc4      1( 0 0 1) =      21.5000      Temp. at max cons.
  36    9 prc5      1( 0 0 1) =      3.40000      shape param for tern
effect
  37   10 prc6      1( 0 0 1) =      13.8000      shape param for tem
effect
  38   11 pmt       1( 0 0 1) =      .000000      daily inst. mort. f
Squaws
  39   12 pvt        ( 0 0 0) =      86400.0      Velocity threshold
feeding
  40   13 pspl      1( 0 0 1) =      .200000      Params- spawning
effect->feeding
  41   14 psp2      1( 0 0 1) =      -.500000          "
  42   15 psp3      1( 0 0 1) =      1.00000           "
  43   16 psf       1( 0 0 1) =      .350000E-02 Params and breakpoi
for
  44   16 psf       2( 0 0 2) =      . 000000     (.11) empirical
distribution
  45   16 psf       3( 0 0 3) =      4.00000        function for
stochastic
  46   16 psf       4( 0 0 4) =      . 000000       functional respon
curve
  47   16 psf       5( 0 0 5) =      .267000
  48   16 psf       6( 0 0 6) =      .150000E-01
  49   16 psf       7( 0 0 7) =      .267000
  50   16 psf       8( 0 0 8) =      . 105000
```

```
   51    16 psf       9( 0 0 9) =        .433000      |
   52    16 psf      10( 0 010) =        .165000      |
   53'   16 psf      11( 0 011) =        .233000      |
   54    16 psf      12( 0 012) =        .230000      |
   55    16 psf      13( 0 013) =        .670000E-01  V
   56    17 psd        ( 0 0 0) =        .432150     Seed for random no.
generator
   57    18 pq        1( 0 0 1) =        .293000E-03 Catchability coeffi
   58    19 pPn  1 1  ( 0 1 1) =        .330000E-01 Distribution of adu
predators
   59    19 pPn  1 2  ( 0 1 2) =        .763000       across areas, sum
1.0
   60    19 pPn  1 3  ( 0 1 3) =        .970000E-01   |
   61    19 pPn  1 4  ( 0 1 4)          .970000E-01   |
   62    19 pPn  1 5  ( 0 1 5) =        .100000E-01   V
   63    20 pmg  1    ( 0 0 1) =        .500000E-01 Migr. rate const.,
m)
   64    21 pae        ( 0 0 0) =        .400000     Assimilation effici
   65    22 pwl        ( 0 0 0) =        .100000E-01 Respiration coeff.
opt temp
   66    23 pw2        ( 0 0 0) =         660000     Respiration exponen
   67    24 pqw  1    ( 1 0 0) =        21.5000     Temp at max respira
rate
   68    24 pqw  2    (2 0 0) =         1.00000     Shape param for
resp-temp
   69    24 pqw  3    (3 0 0) =         1.00000     Shape param for
resp-temp
   70    25 pms  1    ( 1 0 0) =        .900000     Juv. squaw mort., 1
   71    25 pms  2    (2 0 0) =         .750000       annual total
   72    25 pms  3    (3 0 0) =          600000       |
   73    25 pms  4    ( 4 0 0) =        .500000       |
   74    25 pms  5    ( 5 0 0) =        .400000       |
   75    25 pms  6    ( 6 0 0) =        .100000       |
   76    25 pms  7    (7 0 0) =         .500000E-01   |
   77    25 pms  8    ( 8 0 0) =        .100000E-01   |
   78    25 pms  9    ( 9 0 0) =         100000E-01   |
   79    25 pms 10    (10 0 0) =        .100000E-01
   80    26 pme        ( 0 0 0) =        .990000     Egg to age 1 mort.,
   81    27 pli        ( 0 0 0) =        520.000     Loo
   82    28 pbk        ( 0 0 0) =        -162000     Brody growth coef.,
   83    29 pt0        ( 0 0 0) =        .180000E-01 to of VB growth
   84    30 pwl        ( 0 0 0) =        .156000E-04 wt-lngth conv, g/mm
   85    31 plt        ( 0 0 0) =        400.000     length threshold fo
pred., mm
   86    32 pnw        ( 0 0 0) =         600000     Over-winter surviva
   87    33 pww        ( 0 0 0) =        .900000     Over-winter weight
factor
   88    34 prf        ( 0 0 0) =        .500000     g of food/egg
   89    35 pwj        ( 0 0 0) =        2.00000     av. wt. of juv.
salmonid, g
   90    36 psl        ( 0 00) =       153.000      Season length, days
```

```
Parameter input complete   90 recds
Temperature input complete 153 recds
Flow input complete  153 recds
Passage input complete  153 recds
Gonad increment input complete   20 recds
Predator effort input complete   3  recds
Parameters pq(2-5) set to pq(1),   2.930000E-04
Parameters prci(2-5) set to prci(1)
Parameters pspi(2-5) set to pspi(1)
Parameters pmg(2-5) set to pmg(1)

          Time, Driving variables,
                PSV's

  Time      Chin 0   Chin 1   Steelhd  Coho      Sockeye  Flow      Temp    Efrt12
 91.00      99.6     75.2     .000     .000      24.5     .340E+095.35      .000
Gonad inc  .200E-02 .200E-02 .200E-02 .200E-02 .200E-02

Prey   Chin 0      Chin  1  Steelhd      Coho          Sockeye
Area 1   .0000        .  0000  .0000        .0000         .0000
     2   . 0000       .  0000  .0000         0000         .0000
     3   .0000        . 0000 :  0000       : 0000         .0000
     4   . 0000       .  0000  .0000         0000         .0000
     5   .0000       .0000  .   0000       : 0000         .0000
TotPsg   .0000        .  0000  .0000        .0000         .0000
Pred   Squaws
Area 1   1707.       682.7    273.1        109.2          43.69
     2   .3946E+05   .1578E+05 6314.        2526.          1010.
     3   5017.       2007.    802.7        321.1          128.4
     4   5017.       2007.    802.7        321.1          128.4
     5   517.2       206.9    82.75        33.10          13.24
Cons   Chin 0      Chin  1  Steelhd     Coho           Sockeye
squw 1   . 0000       . 0000 .  0000       .0000          .0000
         .0000        .  0000  .0000       . 0000          0000
         .0000        .  0000  .0000       .0000          : 0000
         : 0000 0000  . . 0000 0000 . . 0000 0000  .0000   .0000
                                           .0000          .0000
     2   .0000       .0000       .0000     . 0000         .0000
         . 0000      .0000  .   0000       .0000          .0000
         .0000       .0000  .   0000       .0000          .0000
         .0000        .  0000  .0000       .0000          .0000
          0000        . 0000 .  0000       . 0000         .0000
     3   : 0000       .  0000  .0000       .0000          .0000
         . 0000       .  0000  .0000        0000          .0000
         . 0000       . 0000 .  0000       : 0000         .0000
                                           .0000          .0000
         : 0000 0000  . . 0000 0000 . . 0000 0000  .0000   .0000
     4   .0000       .0000       0000      .0000          .0000
         . 0000      .0000  :    0000      .0000          .0000
         . 0000       .   0000   0000      .0000          .0000
```

| | | | | | |
|---|---|---|---|---|---|
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| 5 | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |
| | .0000 | .0000 | .0000 | .0000 | .0000 |

mort

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | .0000 | .0000 | .0000 | .0000 | .0000 |
| 2 | .0000 | .0000 | .0000 | [illegible] | .0000 |
| 3 | .0000 | .0000 | .0000 | [illegible] | .0000 |
| 4 | .0000 | .0000 | .0000 | .0000 | .0000 |
| 5 | .0000 | .0000 | .0000 | [illegible] | .0000 |
| T | .0000 | .0000 | .0000 | [illegible] | .0000 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .0000 | .0000 | .0000 | .0000 | .0000 |
| 2 | .0000 | .0000 | .0000 | .0000 | .0000 |
| 3 | .0000 | .0000 | .0000 | .0000 | .0000 |
| 4 | .0000 | 0000 | .0000 | .0000 | .0000 |
| 5 | .0000 | .0000 | .0000 | .0000 | .0000 |

Predator lengths by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 420.9 | 420.9 | 420.9 | 420.9 | 420.9 |
| 2 | 435.7 | 435.7 | 435.7 | 435.7 | 435.7 |
| 3 | 448.3 | 448.3 | 448.3 | 448.3 | 448.3 |
| 4 | 459.0 | 459.0 | 459.0 | 459.0 | 459.0 |
| 5 | 468.1 | 468.1 | 468.1 | 468.1 | 468.1 |

Eggs produced = .2057E+10

Juvenile predators:

| | | | | |
|---|---|---|---|---|
| .2057E+08 | .2057E+07 | .5143E+06 | .2057E+06 | .1029E+06 |
| .6172E+05 | .5555E+05 | .5277E+05 | .5224E+05 | .0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

Juvenile predator lengths:

| | | | | |
|---|---|---|---|---|
| 94.04 | 157.7 | 211.9 | 258.0 | 297.2 |
| 330.5 | 358.8 | 382.9 | 403.4 | .0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrtl2 |
|---|---|---|---|---|---|---|---|---|
| 92.00 | 24.5 | 50.7 | 24.5 | .000 | .000 | .378E+09 | 5.85 | .000 |
| Gonad inc | .200E-02 | .200E-02 | .200E-02 | .200E-02 | .200E-02 | | | |

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | 1.202 | .9066 | .0000 | .0000 | .2952 |
| | 2 | 16.79 | 12.26 | .0000 | .0000 | 3.993 |
| | 3 | 44.84 | 30.80 | .0000 | .0000 | 10.03 |
| | 4 | 7.286 | 6.043 | .0000 | .0000 | 1.967 |
| | 5 | .7095 | 2.677 | .0000 | .0000 | .8716 |
| TotPsg | | 99.64 | 75.16 | .0000 | .0000 | 24.47 |

| Pred Squaws | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | 1707. | 682.7 | 273.1' | 109.2 | 43.69 |
| | 2 | .3946E+05 | .1578E+05 | 6314. | 2526. | 1010. |
| | 3 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 4 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 5 | 517.2 | 206.9 | 82.75 | 33.10 | 13.24 |

| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| squw | 1 | .5786 | .4365 | .0000 | .0000 | .1421 |
| | | 13.33 | 9.874 | .0000 | .0000 | 3.215 |
| | | 1.723 | 1.238 | .0000 | .0000 | .4030 |
| | | 1.634 | 1.301 | [illegible] | .0000 | .4236 |
| | | .55633-01 | .2147 | [illegible] | .0000 | .69923-01 |
| | 2 | .2315 | .1746 | [illegible] | .0000 | .5685E-01 |
| | | 5.331 | 3.949 | .0000 | .0000 | 1.286 |
| | | .6892 | .4951 | [illegible] | .0000 | .1612 |
| | | .6537 | .5204 | [illegible] | .0000 | .1694 |
| | | .2225E-01 | .8590E-01 | [illegible] | .0000 | .2797E-01 |
| | 3 | .9258E-01 | .69843-01 | [illegible] | .0000 | .2274E-01 |
| | | 2.133 | 1.580 | [illegible] | .0000 | .5143 |
| | | .2757 | .1980 | [illegible] | .0000 | .6448E-01 |
| | | .2615 | .2082 | [illegible] | .0000 | .67783-01 |
| | | .8902E-02 | .3436E-01 | [illegible] | .0000 | .1119E-01 |
| | 4 | .3703E-01 | .2794E-01 | [illegible] | .0000 | .9096E-02 |
| | | .8530 | .6319 | [illegible] | .0000 | .2057 |
| | | .1103 | .7922E-01 | [illegible] | .0000 | .2579E-01 |
| | | .1046 | .8327E-01 | [illegible] | .0000 | .2711E-01 |
| | | .3561E-02 | .1374E-01 | [illegible] | .0000 | .4475E-02 |
| | 5 | .1481E-01 | .1117E-01 | [illegible] | .0000 | .36383-02 |
| | | .3412 | .2528 | [illegible] | .0000 | .82303-01 |
| | | .4411E-01 | .3169E-01 | [illegible] | .0000 | .1032E-01 |
| | | .4184E-01 | .3331E-01 | [illegible] | .0000 | .1084E-01 |
| | | .1424E-02 | .5498E-02 | [illegible] | .0000 | .1790E-02 |

| mort | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | .9580E-02 | .9580E-02 | [illegible] | .0000 | .9580E-02 |
| | 2 | .2207 | .2167 | [illegible] | .0000 | .2167 |
| | 3 | .2853E-01 | .2716E-01 | [illegible] | .0000 | .2716E-01 |
| | 4 | .2706E-01 | .2856E-01 | [illegible] | .0000 | .2856E-01 |
| | 5 | .9211E-03 | .4713E-02 | [illegible] | .0000 | .4713E-02 |
| | T | .2868 | .2867 | [illegible] | .0000 | .2867 |

Per capita consumption by area

| Area | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Pred | 1 | .6781E-03 | .6694E-03 | .6705E-03 | .66963-03 | .65803-03 |
| | 2. | 67813-03 | .66942-03 | .6705E-03 | .6696E-03 | .6580E-03 |
| | 3 | .6781E-03 | .6694E-03 | .6705E-03 | .6696E-03 | .65803-03 |
| | 4. | 67813-03 | .6694E-03 | .6705E-03 | .66963-03 | .6580E-03 |
| | 5. | 67813-03 | .6694E-03 | .6705E-03 | .6696E-03 | .6580E-03 |

Predator lengths by area

| Area | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Pred | 1 | 420.9 | 420.9 | 420.8 | 420.8 | 420.8 |
| | 2 | 438.0 | 436.6 | 436.0 | 435.8 | 435.7 |
| | 3 | 448.5 | 448.4 | 448.3 | 448.3 | 448.2 |
| | 4 | 459.2 | 459.1 | 459.0 | 459.0 | 459.0 |
| | 5 | 468.1 | 468.1 | 468.1 | 468.1 | 468.1 |

Eggs produced = .2057E+10

Juvenile predators:

| | | | | |
|---|---|---|---|---|
| .2057E+08 | .2057E+07 | .5143E+06 | .2057E+06 | .1029E+06 |
| .6172E+05 | .5555E+05 | .5277E+05 | .5224E+05 | .0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

Juvenile predator lengths:

| | | | | |
|---|---|---|---|---|
| 94.22 | 157.9 | 212.1 | 258.1 | 297.3 |
| 330.6 | 358.9 | 383.0 | 403.5 | .0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 93.00 | 24.5 | 126. | 75.2 | .000 | 24.5 | .372E+09 | 6.10 | .000 |

Gonad inc .200E-02 .200E-02 .200E-02 .200E-02 .200E-02

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | .2946 | .6102 | .2946 | .0000 | .0000 |
| | 2 | 3.662 | 6.147 | 2.515 | .0000 | .3052 |
| | 3 | 51.13 | 43.19 | 10.10 | 0000 | 7.251 |
| | 4 | 7.119 | 9.294 | 2.169 | :0000 | 1.563 |
| | 5 | 1.401 | 6.115 | .9337 | 0000 | 1.361 |
| TotPsg | | 124.1 | 125.9 | 24.47 | :0000 | 24.47 |
| Pred | | Squaws | | | | |
| Area | 1 | 1707. | 682.7 | 273.1 | 109.2 | 43.69 |
| | 2 | .3946E+05 | .1578E+05 | 6314. | 2526, | 1010. |
| | 3 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 4 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 5 | 517.2 | 206.9 | 82.75 | 33.10 | 13.24 |
| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
| Squw | 1 | 9649 | 1.225 | .3770 | 0000 | .1444 |
| | | 27.32 | 25.38 | 4.011 | :0000 | 5.560 |
| | | 3.947 | 2.954 | .2315 | .0000 | .8058 |
| | | 3.489 | 3.276 | .2706 | .0000 | .8842 |
| | | .1292 | .5096 | .2022E-01 | .0000 | .1523 |

| | | | | | |
|---|---|---|---|---|---|
| 2 | .3860 | .4898 | .1508 | .0000 | .5776E-01 |
| | 10.93 | 10.15' | 1.604 | .0000 | 2.224 |
| | 1.579 | 1.182 | .9259E-01 | .0000 | .3223 |
| | 1.395 | 1.311 | .1083 | .0000 | .3537 |
| | .5169E-01 | .2038 | .8088E-02 | .0000 | .6091E-01 |
| 3 | .1544 | .1959 | .6033E-01 | .0000 | .2310E-01 |
| | 4.371 | 4.062 | .6417 | .0000 | .8896 |
| | .6315 | .4727 | .3704E-01 | .0000 | .1289 |
| | .5582 | .5242 | .4330E-01 | .0000 | .1415 |
| | .2068E-01 | .8154E-01 | .3235E-02 | 0000 | .2437E-01 |
| 4 | .6175E-01 | .7837E-01 | .2413E-01 | : 0000 | .9241E-02 |
| | 1.748 | 1.625 | .2567 | .0000 | .3558 |
| | .2526 | .1891 | .1481E-01 | .0000 | .5157E-01 |
| | .2233 | .2097 | .17323-01 | .0000 | .5659E-01 |
| | .8270E-02 | .3262E-01 | .1294E-02 | .0000 | .9746E-02 |
| 5 | .2470E-01 | .3135E-01 | .9652E-02 | .0000 | .3696E-02 |
| | .6994 | .6498 | .1027 | . 0000 | .1423 |
| | .1010 | .7563E-01 | .5926E-02 | .0000 | .2063E-01 |
| | .8931E-01 | .8388E-01 | .6928E-02 | 0000 | .2264E-01 |
| | .3308E-02 | .1305E-01 | .5176E-03 | : 0000 | .3898E-02 |

mort

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | .12833-01 | .1605E-01 | .2542E-01 | .0000 | .9733E-02 |
| 2 | .3631 | .3327 | .2703 | 0000 | .3748 |
| 3 | .5246E-01 | .3872E-01 | .1560E-01 | : 0000 | .5431E-01 |
| 4 | .4637E-01 | .4294E-01 | .1824E-01 | .0000 | .5960E-01 |
| 5 | .1718E-02 | .6679E-02 | .1363E-02 | .0000 | .1027E-01 |
| T | .4765 | .4371 | .3310 | .0000 | .5087 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .9103E-03 | .9086E-03 | .9118E-03 | .9091E-03 | .9108E-03 |
| 2 | .9103E-03 | .9086E-03 | .9118E-03 | .9091E-03 | .9108E-03 |
| 3 | .9103E-03 | .9086E-03 | .9118E-03 | .9091E-03 | .9108E-03 |
| 4 | .91033-03 | .9086E-03 | .9118E-03 | .9091E-03 | .9108E-03 |
| 5 | .9103E-03 | .9086E-03 | .9118E-03 | .9091E-03 | .9108E-03 |

Predator lengths by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 421.0 | 420.8 | 420.8 | 420.8 | 420.7 |
| 2 | 441.1 | 437.8 | 436.5 | 435.9 | 435.7 |
| 3 | 448.8 | 448.4 | 448.3 | 448.2 | 448.2 |
| 4 | 459.5 | 459.1 | 459.0 | 458.9 | 458.9 |
| 5 | 468.1 | 468.0 | 468.0 | 468.0 | 468.0 |

Eggs produced = .2057E+10

Juvenile predators:

| | | | | |
|---|---|---|---|---|
| .2057E+08 | .2057E+07 | .5143E+06 | .2057E+06 | .1029E+06 |
| : 0000 6172E+05 | .5555E+05 | .5277E+05 | .5224E+05 | 0000 |
| | .0000 | .0000 | .0000 | : 0000 |

Juvenile predator lengths:

| | | | | |
|---|---|---|---|---|
| 94.41 | 158.1 | 212.2 | 258.2 | 297.4 |

| | | | | |
|---|---|---|---|---|
| 330.7 | 359.0 | 383.1 | 403.5 | .0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrtl2 |
|---|---|---|---|---|---|---|---|---|
| 94.00 | 24.5 | .237E+04 | 750. | .000 | 50.7 | .400E+09 | 6.40 | .000 |

Gonad inc .200E-02 .200E-02 .200E-02 .200E-02 .200E-02

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | .2791 | 1.435 | .8572 | .0000 | .2791 |
| | 2 | 5.525 | 25.28 | 14.62 | .0000 | 4.798 |
| | 3 | 57.77 | 85.26 | 39.48 | .0000 | 15.69 |
| | 4 | 8.061 | 20.49 | 9.303 | .0000 | 3.750 |
| | 5 | 1.730 | 11.88 | 4.578 | .0000 | 2.224 |
| TotPsg | | 148.6 | 251.7 | 99.64 | .0000 | 48.94 |

Pred Squaws

| | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | 1707. | 682.7 | 273.1 | 109.2 | 43.69 |
| | 2 | .3946E+05 | .1578E+05 | 6314. | 2526. | 1010. |
| | 3 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 4 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 5 | 517.2 | 206.9 | 82.75 | 33.10 | 13.24 |

| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| squw | 1 | 1.121 | 2.013 | .8471 | .0000 | .2961 |
| | | 32.30 | 43.44 | 13.96 | .0000 | 8.590 |
| | | 5.570 | 4.863 | .9653 | 0000 | 1.145 |
| | | 4.642 | 5.483 | 1.103 | .0000 | 1.275 |
| | | .1826 | .7955 | .9906E-01 | .0000 | .2085 |
| | 2 | .4483 | .8053 | .3388 | 0000 | .1184 |
| | | 12.92 | 17.38 | 5.585 | .0000 | 3.436 |
| | | 2.228 | 1.945 | .3861 | 0000 | .4582 |
| | | 1.857 | 2.193 | .4411 | .0000 | .5101 |
| | | .7305E-01 | .3182 | .3962E-01 | .0000 | .8340E-01 |
| | 3 | .1793 | .3221 | .1355 | .0000 | .4737E-01 |
| | | 5.168 | 6.951 | 2.234 | 0000 | 1.374 |
| | | .8912 | .7780 | .1544 | .0000 | .1833 |
| | | .7428 | .8774 | .1764 | .0000 | .2041 |
| | | .2922E-01 | .1273 | .1585E-01 | 0000 | .3336E-01 |
| | 4 | .7173E-01 | .1288 | .5421E-01 | .0000 | .18953-01 |
| | | 2.067 | 2.780 | .8936 | .0000 | .5497 |
| | | .3565 | .3112 | .6178E-01 | 0000 | .7331E-01 |
| | | .2971 | .3509 | .7058E-01 | .0000 | .8162E-01 |
| | | .1169E-01 | .5091E-01 | .6340E-02 | .0000 | .1334E-01 |
| | 5 | .2869E-01 | .5154E-01 | .2168E-01 | .0000 | .7579E-02 |
| | | .8269 | 1.112 | .3574 | 0000 | .2199 |
| | | .1426 | .1245 | .2471E-01 | .0000 | .2932E-01 |
| | | .1188 | .1404 | .2823E-01 | .0000 | .3265E-01 |
| | | .4675E-02 | .2036E-01 | .2536E-02 | .0000 | .5338E-02 |

mort

| | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | .1244E-01 | .1319E-01 | .1402E-01 | .0000 | .9978E-02 |
| | 2 | .3586 | .2847 | .2312 | .0000 | .2895 |
| | 3 | .6184E-01 | .3187E-01 | .1598E-01 | 0000 | .38613-01 |

| | | | | | |
|---|---|---|---|---|---|
| 4 | .5154E-01 | .3594E-01 | .1826E-01 | .0000 | .4298E-01 |
| 5 | .2028E-02 | .5213E-02 | .16403-02 | 0000 | .7027E-02 |
| T | .4865 | .3709 | .2811 | : 0000 | .3881 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .9176E-03 | .9128E-03 | .9180E-03 | .9137E-03 | .9171E-03 |
| 2 | .9176E-03 | .9128E-03 | .9180E-03 | .9137E-03 | .9171E-03 |
| 3 | .9176E-03 | .9128E-03 | .9180E-03 | .9137E-03 | .91713-03 |
| 4 | .9176E-03 | .9128E-03 | .9180E-03 | .9137E-03 | .9171E-03 |
| 5 | .9176E-03 | .9128E-03 | .9180E-03 | .9137E-03 | .9171E-03 |

Predator lengths by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 421.1 | 420.8 | 420.7 | 420.7 | 420.7 |
| 2 | 444.2 | 439.0 | 436.9 | 436.1 | 435.7 |
| 3 | 449.2 | 448.5 | 448.3 | 448.2 | 448.1 |
| 4 | 459.8 | 459.2 | 459.0 | 458.9 | 458.8 |
| 5 | 468.0 | 468.0 | 467.9 | 467.9 | 467.9 |

Eggs produced = .2057E+10

Juvenile predators:

| | | | | |
|---|---|---|---|---|
| . 2057E+08 | .2057E+07 | .5143E+06 | .2057E+06 | .1029E+06 |
| . 6172E+05 | .5555E+05 | .5277E+05 | .5224E+05 | .0000 |
| .0000 | . 0000 | .0000 | .0000 | .0000 |

Juvenile predator lengths:

| | | | | |
|---|---|---|---|---|
| 94.60 | 158.2 | 212.3 | 258.3 | 297.5 |
| 330.8 | 359.1 | 383.1 | 403.6 | .0000 |
| . 0000 | .0000 | . 0000 | .0000 | .0000 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 95.00 | .000 | .450E+05 | 949. | .000 | 75.2 | .426E+09 | 6.70 | .000 |

Gonad inc .200E-02 .200E-02 .200E-02 .200E-02 .200E-02

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | .2636 | 25.55 | 8.077 | .0000 | .5460 |
| 2 | 13.70 | 823.7 | 265.0 | .0000 | 20.82 |
| 3 | 65.92 | 1110. | 360.8 | .0000 | 34.40 |
| 4 | 10.40 | 285.5 | 93.40 | .0000 | 9.602 |
| 5 | 2.364 | 138.3 | 45.87 | 0000 | 5,464 |
| TotPsg | 173.1 | 2624. | 849.5 | : 0000 | 99.64 |
| Pred Squaws | | | | | |
| Area 1 | 1707. | 682.7 | 273.1 | 109.2 | 43.69 |
| 2 | .3946E+05 | .1578E+05 | 6314. | 2526. | 1010. |
| 3 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| 4 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| 5 | 517.2 | 206.9 | 82.75 | 33.10 | 13.24 |

| Cons | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| squw 1 | 1.140 | 3.678 | 1.376 | .0000 | .3333 |

| | | | | | |
|---|---|---|---|---|---|
| | 33.40 | 78.53 | 25.92 | .0000 | 9.905 |
| | 6.153 | 9.094 | 2.416 | .0000 | 1.359 |
| | 5.018 | 9.723 | 2.570 | .0000 | 1.511 |
| | .2059 | 1.241 | .2574 | .0000 | .2461 |
| 2 | .4559 | 1.471 | .5505 | .0000 | .1333 |
| | 13.36 | 31.41 | 10.37 | . 0000 | 3.962 |
| | 2.461 | 3.638 | .9663 | .0000 | .5438 |
| | 2.007 | 3.889 | 1.028 | .0000 | .6045 |
| | .8237E-01 | .4964 | .1030 | .0000 | .98423-01 |
| 3 | 1823 | .5886 | .2202 | [illegible] | .5332E-01 |
| | 5.344 | 12.56 | 4.147 | [illegible] | 1.585 |
| | .9845 | 1.455 | .3865 | [illegible] | .2175 |
| | .8028 | 1.556 | .4112 | [illegible] | .2418 |
| | .3295E-01 | .1985 | .4118E-01 | [illegible] | .3937E-01 |
| 4 | .7294E-01 | .2354 | .8807E-01 | [illegible] | .2133E-01 |
| | 2.138 | 5.026 | 1.659 | [illegible] | .6339 |
| | .3938 | .5820 | .1546 | [illegible] | .8700E-01 |
| | .3211 | .6223 | .1645 | [illegible] | .96723-01 |
| | .1318E-01 | .7942E-01 | .1647E-01 | [illegible] | .1575E-01 |
| 5 | .2918E-01 | .9417E-01 | .3523E-01 | [illegible] | .85323-02 |
| | .8550 | 2.010 | .6635 | [illegible] | .2536 |
| | .1575 | .2328 | .6184E-01 | [illegible] | .3480E-01 |
| | .1285 | .2489 | .6579E-01 | [illegible] | .3869E-01 |
| | .5272E-02 | .3177E-01 | .6589E-02 | [illegible] | .6299E-02 |
| mort | | | | | |
| Area 1 | .1086E-01 | .2313E-02 | .2672E-02 | [illegible] | .5518E-02 |
| 2 | .3184 | .4937E-01 | .5033E-01 | [illegible] | .1640 |
| 3 | .5866E-01 | .5718E-02 | .4691E-02 | [illegible] | .2251E-01 |
| 4 | .47833-01 | .61133-02 | .4991E-02 | [illegible] | .2502E-01 |
| 5 | .1963E-02 | .7802E-03 | .4998E-03 | [illegible] | .4074E-02 |
| T | .4377 | .64293-01 | .6318E-01 | [illegible] | .2211 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .1319E-02 | .1253E-02 | .1291E-02 | .1259E-02 | .1285E-02 |
| 2 | .1319E-02 | .1253E-02 | .1291E-02 | .1259E-02 | .1285E-02 |
| 3 | .1319E-02 | .1253E-02 | .1291E-02 | .1259E-02 | .1285E-02 |
| 4 | .1319E-02 | .1253E-02 | .1291E-02 | .1259E-02 | .12853-02 |
| 5 | . 1319E-02 | .1253E-02 | .1291E-02 | .1259E-02 | .12853-02 |

Predator lengths by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 421.2 | 420.8 | 420.7 | 420.6 | 420.6 |
| 2 | 448.3 | 440.7 | 437.5 | 436.3 | 435.7 |
| 3 | 449.6 | 448.7 | 448.3 | 448.1 | 448.1 |
| 4 | 460.3 | 459.3 | 459.0 | 458.8 | 458.8 |
| 5 | 468.0 | 467.9 | 467.9 | 467.9 | 467.9 |

Eggs produced = .2057E+10

Juvenile predators:

| | | | | |
|---|---|---|---|---|
| .2057E+08 | .2057E+07 | .5143E+06 | .2057E+06 | .1029E+06 |
| . 6172E+05 | .5555E+05 | .5277E+05 | .5224E+05 | .0000 |

| | | | | |
|---|---|---|---|---|
| .0000 | .0000 | .0000 | .0000 | .0000 |

Juvenile predator lengths:

| | | | | |
|---|---|---|---|---|
| 94.79 | 158.4 | 212.5 | 258.5 | 297.6 |
| 330.8 | 359.1 | 383.2 | 403.7 | .0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 96.00 | .000 | .136E+06725. | | .000 | 48.9 | .374E+096.70 | | .000 |

Gonad inc .200E-02 .200E-02 .200E-02 .200E-02 .200E-02

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | [illegible] | 553.3 | 11.66 | 0000 | .9236 |
| | 2 | 13.62 | .1676E+05 | 557.4 | : 0000 | 44.29 |
| | 3 | 62.73 | .2082E+05 | 710.0 | .0000 | 60.65 |
| | 4 | 10.90 | 5459. | 218.7 | .0000 | 19.48 |
| | 5 | 2.462 | 2644. | 131.7 | .0000 | 11.73 |
| TotPsg | | 173.1 | .4765E+05 | 1799. | .0000 | 174.8 |

| Pred | | Squaws | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | 1707. | 682.7 | 273.1 | 109.2 | 43.69 |
| | 2 | .3946E+05 | .1578E+05 | 6314. | 2526. | 1010. |
| | 3 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 4 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 5 | 517.2 | 206.9 | 82.75 | 33.10 | 13.24 |

| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| squw | 1 | 1.140 | 8.652 | 1.486 | .0000 | .3419 |
| | | 33.52 | 126.6 | 29.01 | .0000 | 10.15 |
| | | 6.226 | 18.27 | 2.963 | .0000 | 1.409 |
| | | 5.057 | 16.14 | 3.055 | .0000 | 1.558 |
| | | .2090 | 2.115 | .3520 | .0000 | .2557 |
| | 2 | .4559 | 3.461 | .5944 | .0000 | .1368 |
| | | 13.41 | 50.66 | 11.60 | 0000 | 4.060 |
| | | 2.490 | 7.307 | 1.185 | : 0000 | .5635 |
| | | 2.023 | 6.456 | 1.222 | .0000 | .6231 |
| | | .8359E-01 | .8460 | .1408 | 0000 | .1023 |
| | 3 | .1824 | 1.384 | .2378 | : 0000 | .5470E-01 |
| | | 5.363 | 20.26 | 4.641 | 0000 | 1.624 |
| | | .9962 | 2.923 | .4741 | : 0000 | .2254 |
| | | .8092 | 2.582 | .4888 | .0000 | .2493 |
| | | .3343E-01 | .3384 | .5631E-01 | .0000 | .4092E-01 |
| | 4 | .7295E-01 | .5537 | .9510E-01 | :0000 | .2188E-01 |
| | | 2.145 | 8.105 | 1.857 | 0000 | .6496 |
| | | .3985 | 1.169 | .1896 | .0000 | .9016E-01 |
| | | .3237 | 1.033 | .1955 | .0000 | .9970E-01 |
| | | .1337E-01 | .1354 | .2253E-01 | .0000 | .16373-01 |
| | 5 | .2918E-01 | .2215 | .3804E-01 | :0000 | .8753E-02 |
| | | .8581 | 3.242 | .7426 | 0000 | .2598 |
| | | .1594 | .4677 | .7586E-01 | :0000 | .36063-01 |
| | | .1295 | .4132 | .7820E-01 | 0000 | .3988E-01 |
| | | .5350E-02 | .5414E-01 | .9010E-02 | .0000 | .6546E-02 |

mort

| | | | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | .1087E-01 | .2995E-03 | .1363E-02 | .0000 | .32273-02 |
| | 2 | .3195 | . 43853-02 | .2660E-01 | .0000 | .95783-01 |
| | 3 | .5935E-01 | .6324E-03 | .2718E-02 | .0000 | .1329E-01 |
| | 4 | .4821E-01 | .5588E-03 | .2802E-02 | .0000 | .1470E-01 |
| | 5 | .19923-02 | .7322E-04 | .3228E-03 | .0000 | .2413E-02 |
| | T | .4399 | .5948E-02 | .3381E-01 | .0000 | .1294 |

Per capita consumption by area

| Area | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Pred | 1 | .2983E-02 | .1307E-02 | .1962E-02 | .1393E-02 | .1897E-02 |
| | 2 | .2983E-02 | .1307E-02 | .1962E-02 | .1393E-02 | .18973-02 |
| | 3 | .2983E-02 | .1307E-02 | .1962E-02 | .1393E-02 | .1897E-02 |
| | 4 | .2983E-02 | .1307E-02 | .1962E-02 | .13933-02 | .18973-02 |
| | 5 | .2983E-02 | .1307E-02 | .1962E-02 | .1393E-02 | .1897E-02 |

Predator lengths by area

| Area | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Pred | 1 | 421.6 | 421.0 | 420.7 | 420.6 | 420.5 |
| | 2 | 452.6 | 442.4 | 438.2 | 436.5 | 435.8 |
| | 3 | 450.4 | 448.9 | 448.3 | 448.1 | 448.0 |
| | 4 | 460.7 | 459.5 | 459.0 | 458.8 | 458.7 |
| | 5 | 468.0 | 467.9 | 467.8 | 467.8 | 467.8 |

Eggs produced = .2057E+10

Juvenile predators:

| | | | | |
|---|---|---|---|---|
| .2057E+08 | .2057E+07 | .5143E+06 | .2057E+06 | .1029E+06 |
| .6172E+05 | .5555E+05 | .5277E+05 | .5224E+05 | .0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

Juvenile predator lengths:

| | | | | |
|---|---|---|---|---|
| 94.98 | 158.5 | 212.6 | 258.6 | 297.7 |
| 330.9 | 359.2 | 383.3 | 403.7 | .0000 |
| . 0000 | . 0000 | .0000 | .0000 | .0000 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrtl2 |
|---|---|---|---|---|---|---|---|---|
| 97.00 | 150. | .133E+06 | 998. | .000 | 75.2 | .345E+09 | 6.70 | .000 |

Gonad inc .200E-02 .200E-02 .200E-02 .200E-02 .200E-02

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | .0000 | 1819. | 9.669 | .0000 | 54.38 6524 |
| | 2 | 13.57 | . 6271E+05 | 720.8 | .0000 | |
| | 3 | 59.61 | .7716E+05 | 892.3 | .0000 | 70.32 |
| | 4 | 11.38 | .2207E+05 | 333.2 | | |
| | 5 | 2.511 | . 1209E+05 | 218.7 | : 0000 0000 | 27.51 17.89 |
| **TotPsg** | | 173.1 | . 1841E+06 | 2524. | .0000 | 223.7 |

| Pred | | Squaws | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | 1707. | 682.7 | 273.1 | 109.2 | 43.69 |
| | 2 | .3946E+05 | .1578E+05 | 6314. | 2526. | 1010. |
| | 3 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 4 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 5 | 517.2 | 206.9 | 82.75 | 33.10 | 13.24 |
| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
| squw | 1 | 1.140 | 44.48 | 1.678 | .0000 | .3549 |
| | | 33.54 | 185.2 | 30.03 | .0000 | 10.23 |
| | | 6.275 | 60.87 | 3.619 | 0000 | 1.462 |
| | | 5.067 | 26.35 | 3.277 | .0000 | 1.577 |
| | | .2114 | 9.460 | .5296 | 0000 | .2707 |
| | 2 | .4559 | 17.79 | .6711 | .0000 | .1419 |
| | | 13.42 | 74.08 | 12.01 | .0000 | 4.091 |
| | | 2.510 | 24.35 | 1.448 | .0000 | .5848 |
| | | 2.027 | 10.54 | 1.311 | .0000 | .6308 |
| | | .8454E-01 | 3.784 | .2118 | .0000 | .1083 |
| | 3 | .1824 | 7.116 | .2684 | .0000 | .5678E-01 |
| | | 5.367 | 29.63 | 4.805 | .0000 | 1.637 |
| | | 1.004 | 9.739 | .5791 | .0000 | .2339 |
| | | .8106 | 4.216 | .5244 | .0000 | .2523 |
| | | .3382E-01 | 1.514 | .8474E-01 | 0000 | .4331E-01 |
| | 4 | .7295E-01 | 2.847 | .1074 | .0000 | .2271E-01 |
| | | 2.147 | 11.85 | 1.922 | 0000 | .6546 |
| | | .4016 | 3.896 | .2316 | .0000 | .9357E-01 |
| | | .3243 | 1.686 | .2098 | .0000 | .1009 |
| | | .1353E-01 | .6054 | .3390E-01 | .0000 | .1732E-01 |
| | 5 | .2918E-01 | 1.139 | .4295E-01 | .0000 | .90843-02 |
| | | .8587 | 4.741 | .7688 | 0000 | .2619 |
| | | .1606 | 1.558 | .9266E-01 | .0000 | .3743E-01 |
| | | .1297 | .6746 | .8390E-01 | 0000 | .4037E-01 |
| | | .5411E-02 | .2422 | .1356E-01 | .0000 | .6929E-02 |
| mort | | | | | | |
| Area | 1 | .1087E-01 | .3985E-03 | .1096E-02 | .0000 | .2616E-02 |
| | 2 | [illegible] | .1660E-02 | .1963E-01 | .0000 | .7541E-01 |
| | 3 | .5982E-01 | .5454E-03 | .2365E-02 | .0000 | .1078E-01 |
| | 4 | .4830E-01 | .2361E-03 | .2142E-02 | .0000 | .1163E-01 |
| | 5 | .2015E-02 | .8477E-04 | .3461E-03 | .0000 | .1995E-02 |
| | T | .4407 | .2924E-02 | .2558E-01 | .0000 | .1024 |

Per capita consumption by area

| Area | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Pred | 1 | .2111E-01 | .1513E-02 | .8643E-02 | .2085E-02 | .1458E-01 |
| | 2 | .2111E-01 | .1513E-02 | .8643E-02 | .2085E-02 | .1458E-01 |
| | 3 | .2111E-01 | .1513E-02 | .8643E-02 | .2085E-02 | .1458E-01 |
| | 4 | .2111E-01 | .1513E-02 | .8643E-02 | .2085E-02 | .1458E-01 |
| | 5 | .2111E-01 | .1513E-02 | .8643E-02 | .2085E-02 | .1458E-01 |

Predator lengths by area

| Area | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Pred | 1 | 425.0 | 422.3 | 421.2 | 420.7 | 420.5 |
| | 2 | 457.4 | 444.4 | 439.0 | 436.7 | 435.8 |
| | 3 | 453.9 | 450.3 | 448.8 | 448.2 | 448.0 |
| | 4 | 461.5 | 459.8 | 459.0 | 458.8 | 458.7 |
| | 5 | 468.5 | 468.0 | 467.8 | 467.7 | 467.7 |

Eggs produced = .2057E+10

Juvenile predators:

| | | | | |
|---|---|---|---|---|
| .2057E+08 | .2057E+07 | .5143E+06 | .2057E+06 | .1029E+06 |
| .6172E+05 | .5555E+05 | .5277E+05 | .5224E+05 | .0000 |
| .0000 | .0000 | .0000 | .0000 | . 0000 |

Juvenile predator lengths:

| | | | | |
|---|---|---|---|---|
| 95.17 | 158.7 | 212.7 | 258.7 | 297.8 |
| 331.0 | 359.3 | 383.3 | 403.8 | . 0000 |
| . 0000 | .0000 | .0000 | . 0000 | . 0000 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 98.00 | .000 | .135E+06 | .117E+04 | .000 | 99.6 | .334E+09 | 6.70 | .000 |

Gonad inc .200E-02 .200E-02 .200E-02 .200E-02 .200E-02

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | 2.070 | 1831. | 13.75 | .0000 | 1.035 |
| | 2 | 71.66 | .9951E+05 | 952.4 | .0000 | 71.97 |
| | 3 | 129.0 | .1210E+06 | 1158. | .0000 | 89.62 |
| | 4 | 27.12 | .4105E+05 | 479.6 | .0000 | 38.36 |
| | 5 | 4.065 | .2597E+05 | 303.0 | .0000 | 23.76 |
| TotPsg | | 323.4 | .3171E+06 | 3522. | .0000 | 298.9 |

| Pred | | Squaws | | | | |
|---|---|---|---|---|---|---|
| Area | 1 | 1707. | 682.7 | 273.1 | 109.2 | 43.69 |
| | 2 | .3946E+05 | .1578E+05 | 6314. | 2526. | 1010. |
| | 3 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 4 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 5 | 517.2 | 206.9 | 82.75 | 33.10 | 13.24 |

| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| squw | 1 | 1.179 | 80.05 | 1.944 | .0000 | .3749 |
| | | 33.58 | 256.6 | 30.77 | .0000 | 10.28 |
| | | 6.444 | 237.8 | 5.427 | .0000 | 1.603 |
| | | 5.079 | 46.16 | 3.533 | .0000 | 1.598 |
| | | .2184 | 53.11 | 1.130 | .0000 | .3186 |
| | 2 | .4718 | 32.02 | .7774 | .0000 | 1499 |
| | | 13.43 | 102.6 | 12.31 | .0000 | 4.114 |
| | | 2.578 | 95.12 | 2.171 | .0000 | .6411 |
| | | 2.031 | 18.47 | 1.413 | .0000 | .6391 |
| | | . 8736E-01 | 21.24 | .4521 | .0000 | .1274 |
| | 3 | .1887 | 12.81 | .3110 | .0000 | .5998E-01 |
| | | 5.373 | 41.06 | 4.923 | .0000 | 1.646 |
| | | 1.031 | 38.05 | .8683 | .0000 | .2565 |
| | | .3494E-01 8126 | 7.386 | .5653 | .0000 | .2556 |
| | | | 8.497 | i-1809 | .0000 | .5097E-01 |
| | 4 | 7549E-01 | 5.123 | .1244 | .0000 | .2399E-01 |
| | | 2.149 | 16.42 | 1.969 | .0000 | .6582 |
| | | .4124 | 15.22 | .3473 | .0000 | .1026 |
| | | . 3250 | 2.954 | .2261 | .0000 | .1022 |
| | | . 1398E-01 | 3.399 | .7234E-01 | .0000 | .2039E-01 |
| | 5 | .3020E-01 | 2.049 | .4976E-01 | .0000 | .9596E-02 |

| | | | | | |
|---|---|---|---|---|---|
| | .8596 | 6.570 | .7877 | .0000 | .2633 |
| | .1650 | 6.088 | .1389 | .0000 | .4103E-01 |
| | .1300 | 1.182 | .9045E-01 | .0000 | .4090E-01 |
| | .5591E-02 | 1.360 | .2894E-01 | .0000 | .8155E-02 |
| mort | | | | | |
| Area 1 | .6017E-02 | .4165E-03 | .9103E-03 | .0000 | .2069E-02 |
| 2 | .1713 | .1335E-02 | .1441E-01 | .0000 | .5676E-01 |
| 3 | .3287E-01 | .1237E-02 | .2542E-02 | .0000 | .8846E-02 |
| 4 | .2591E-01 | .2402E-03 | .1655E-02 | .0000 | .8817E-02 |
| 5 | .1114E-02 | .2763E-03 | .5294E-03 | .0000 | .1758E-02 |
| T | .2372 | .3505E-02 | .2005E-01 | .0000 | .7825E-01 |

Per capita consumption.by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .2103E-01 | .1831E-02 | .3569E-01 | .4007E-02 | .8566E-01 |
| 2 | .2103E-01 | .1831E-02 | .3569E-01 | .4007E-02 | .8566E-01 |
| 3 | .2103E-01 | .1831E-02 | .3569E-01 | .4007E-02 | .8566E-01 |
| 4 | .2103E-01 | .1831E-02 | .3569E-01 | .4007E-02 | .8566E-01 |
| 5 | .2103E-01 | .1831E-02 | .3569E-01 | .4007E-02 | .8566E-01 |

Predator lengths by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 428.3 | 423.6 | 421.6 | 420.9 | 420.6 |
| 2 | 463.2 | 446.8 | 439.9 | 437.1 | 435.9 |
| 3 | 456.8 | 456.2 | 451.2 | 449.1 | 448.3 |
| 4 | 463.0 | 460.3 | 459.2 | 458.8 | 458.6 |
| 5 | 471.9 | 469.3 | 468.3 | 467.9 | 467.7 |

Eggs produced = .2057E+10

Juvenile predators:

| | | | | |
|---|---|---|---|---|
| .2057E+08 | .2057E+07 | .5143E+06 | .2057E+06 | .1029E+06 |
| .6172E+05 | .5555E+05 | .5277E+05 | .5224E+05 | .0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

Juvenile predator lengths:

| | | | | |
|---|---|---|---|---|
| 95.36 | 158.9 | 212.9 | 258.8 | 297.9 |
| 331.1 | 359.3 | 383.4 | 403.8 | .0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

```
  Time     Chin 0   Chin 1   Steelhd Coho     Sockeye  Flow     Temp   Efrt12
 99.00     325.     .818E+05.157E+04.000      24.5     .349E+096.70     .000
Gonad inc   .200E-02 .200E-02 .200E-02 .200E-02 .200E-02
```

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | .0000 | 1787. | 15.50 | .0000 | 1.317 |
| 2 | 70.12 | .1306E+06 | 1207. | .0000 | 95.29 |
| 3 | 123.7 | .1571E+06 | 1451. | .0000 | 116.1 |
| 4 | 28.65 | .6156E+05 | 650.4. | .0000 | 52.34 |
| 5 | 5,736 | .3975E+05 | 398.1 | .0000 | 31.29 |
| TotPsg | 323.4 | .4523E+06 | 4695. | .0000 | 398.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Pred | Squaws | | | | | |
| Area | 1 | 1707. | 32.7 | 273.1 | 109.2 | 43.69 |
| | 2 | .3946E+05 | .1578E+05 | 6314. | 2526. | 1010. |
| | 3 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 4 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 5 | 517.2 | 206.9 | 82.75 | 33.10 | 13.24 |
| Cons | | Chin o | Chin 1 | Steelhd | Coho | sockeye |
| squw | 1 | 1.180 | 122.5 | 2.311 | 0000 | .4060 |
| | | 33.63 | 340.1 | 31.55 | : 0000 | 10.35 |
| | | 6.765 | 591.4 | 8.740 | .0000 | 1.864 |
| | | 5.100 | 86.03 | 3.971 | .0000 | 1.633 |
| | | .2266 | 106.5 | 1.700 | .0000 | .3632 |
| | 2 | .4720 | 48.99 | .9244 | .0000 | .1624 |
| | | 13.45 | 136.1 | 12.62 | .0000 | 4.138 |
| | | 2.706 | 236.6 | 3.496 | .0000 | .7457 |
| | | 2.040 | 34.41 | 1.589 | .0000 | .6531 |
| | | .9065E-01 | 42.59 | .6802 | .0000 | .1453 |
| | 3 | .1888 | 19.60 | .3697 | .0000 | .6496E-01 |
| | | 5.381 | 54.42 | 5.048 | 0000 | 1.655 |
| | | 1.082 | 94.63 | 1.398 | : 0000 | .2983 |
| | | .8160 | 13.76 | .6354 | .0000 | .2612 |
| | | .3626E-01 | 17.04 | .2721 | 0000 | .5811E-01 |
| | 4 | .7553E-01 | 7.838 | .1479 | : 0000 | .2599E-01 |
| | | 2.152 | 21.77 | 2.019 | .0000 | .6621 |
| | | .4329 | 37.85 | .5594 | 0000 | .1193 |
| | | .3264 | 5.506 | .2542 | : 0000 | .1045 |
| | | .1450E-01 | 6.815 | .1088 | . 0000 | .2324E-01 |
| | 5 | .3021E-01 | 3.135 | .5916E-01 | .0000 | .1039E-01 |
| | | .8609 | 8.708 | .8077 | . 0000 | .2648 |
| | | .1732 | 15.14 | .2237 | .0000 | .4772E-01 |
| | | .1306 | 2.202 | .1017 | .0000 | .4180E-01 |
| | | .5802E-02 | 2.726 | .4353E-01 | .0000 | .9297E-02 |
| mort | | | | | | |
| Area | 1 | .60203-02 | .4467E-03 | .8119E-03 | .0000 | .1681E-02 |
| | 2 | .1716 | .1241E-02 | .1109E-01 | .0000 | .4282E-01 |
| | 3 | .3451E-01 | .2157E-02 | .3071E-02 | .0000 | .7716E-02 |
| | 4 | .2602E-01 | .3138E-03 | .1395E-02 | .0000 | .6758E-02 |
| | 5 | .1156E-02 | .3884E-03 | .5974E-03 | .0000 | .1503E-02 |
| | T | .2393 | .4546E-02 | .1696E-01 | . 0000 | .6048E-01 |

Per capita consumption by area

| Area | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Pred | 1 | .2509E-01 | .2139E-02 | .7127E-01 | .8045E-02 | .1044 |
| | 2 | .2509E-01 | .2139E-02 | .7127E-01 | .8045E-02 | .1044 |
| | 3 | .2509E-01 | .2139E-02 | .7127E-01 | .8045E-02 | .1044 |
| | 4 | .2509E-01 | .2139E-02 | .7127E-01 | .8045E-02 | .1044 |
| | 5 | .2509E-01 | .2139E-02 | .7127E-01 | .8045E-02 | .1044 |

Predator lengths by area

| Area | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Pred | 1 | 432.1 | 425.1 | 422.2 | 421.0 | 420.6 |
| | 2 | 469.7 | 449.6 | 441.0 | 437.5 | 436.0 |

| | | | | | |
|---|---|---|---|---|---|
| 3 | 440.0 | 463.0 | 455.9 | 451.0' | 449.0 |
| 4 | 466.2 | 461.5 | 459.7 | 458.9 | 458.6 |
| 5 | 475.9 | 470.9 | 468.9 | 468.1 | 467.8 |

Eggs produced = .2057E+10

Juvenile predators:

| | | | | |
|---|---|---|---|---|
| .2057E+08 | .2057E+07 | .5143E+06 | .2057E+06 | 1029E+06 |
| .6172E+05 | .5555E+05 | .5277E+05 | .5224E+05 | : 0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

Juvenile predator lengths:

| | | | | |
|---|---|---|---|---|
| 95.54 | 159.0 | 213.0 | 258.9 | 298.0 |
| 331.2 | 359.4 | 383.4 | 403.9 | .0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 100.00 | 124. | .703E+05 | .117E+04 | .000 | 75.2 | .392E+09 | 6.70 | .000 |
| Gonad inc | .200E-02 | .200E-02 | .200E-02 | .200E-02 | .200E-02 | | | |

| Prey | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| Area | 1 | 3.816 | 960.0 | 18.46 | .0000 | .2872 |
| | 2 | 193.9 | .1371E+06 | 1562. | .0000 | 87.63 |
| | 3 | 274.6 | .1626E+06 | 1865. | .0000 | 104.4 |
| | 4 | 62.97 | .7645E+05 | 870.2 | .0000 | 58.30 |
| | 5 | 9.656 | .4938E+05 | 515.1 | .0000 | 35.52 |
| TotPsg | | 648.5 | .5341E+06 | 6268. | .0000 | 423.0 |
| Pred | | Squaws | | | | |
| Area | 1 | 1707. | 682.7 | 273.1 | 109.2 | 43.69 |
| | 2 | .3946E+05 | .1578E+05 | 6314. | 2526. | 1010. |
| | 3 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 4 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 5 | 517.2 | 206.9 | 82.75 | 33.10 | 13.24 |
| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
| Squw | 1 | 1.225 | 134.1 | 2.530 | .0000 | .4097 |
| | | 33.72 | 431.0 | 32.49 | .0000 | 10.41 |
| | | 7.295 | 1020. | 13.19 | .0000 | 2.159 |
| | | 5.148 | 157.9 | 4.762 | .0000 | 1.690 |
| | | .2352 | 160.0 | 2.239 | .0000 | .4036 |
| | 2 | .4898 | 53.64 | 1.012 | .0000 | .1639 |
| | | 13.49 | 172.4 | 13.00 | .0000 | 4.163 |
| | | 2.918 | 408.0 | 5.276 | .0000 | .8638 |
| | | 2.059 | 63.18 | 1.905 | .0000 | .6762 |
| | | .9407E-01 | 64.01 | .8956 | .0000 | .1614 |
| | 3 | .1959 | 21.45 | .4048 | .0000 | .6555E-01 |
| | | 5.395 | 68.97 | 5.199 | .0000 | 1.665 |
| | | 1.167 | 163.2 | 2.110 | .0000 | .3455 |
| | | .8237 | 25.27 | .7619 | .0000 | .2705 |
| | | .37633-01 | 25.60 | .3582 | .0000 | .6457E-01 |
| | 4 | 7837E-01 | 8.582 | .1619 | .0000 | .2622E-01 |
| | | 2.158 | 27.59 | 2.080 | .0000 | .6661 |

| | | | | | |
|---|---|---|---|---|---|
| | .4669 | 65.27 | .8441 | .0000 | .1382 |
| | .3295 | 10.11 | .3048 | .0000 | .1082 |
| | .1505E-01 | 10.24 | .1433 | .0000 | .2583E-01 |
| 5 | .3135E-01 | 3.433 | .6477E-01 | .0000 | .1049E-01 |
| | .8632 | 11.03 | .8318 | .0000 | .2664 |
| | .1867 | 26.11 | .3376 | .0000 | .5528E-01 |
| | .1318 | 4.043 | .1219 | 0000 | .4328E-01 |
| | .6020E-02 | 4.097 | .5732E-01 | : 0000 | .1033E-01 |

mort

| | | | | | |
|---|---|---|---|---|---|
| Area 1 | .3115E-02 | .4142E-03 | .6658E-03 | .0000 | .1598E-02 |
| 2 | .8577E-01 | .1331E-02 | .8551E-02 | .0000 | .4058E-01 |
| 3 | .1856E-01 | .3150E-02 | .3471E-02 | .0000 | .8421E-02 |
| 4 | .1309E-01 | .4878E-03 | .12533-02 | .0000 | .6592E-02 |
| 5 | .5982E-03 | .4942E-03 | .5892E-03 | 0000 | .1574E-02 |
| T | .1211 | .5878E-02 | .14533-01 | : 0000 | .5877E-01 |

Per capita consumption by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | .6966E-02 | .2331E-02 | .8646E-01 | .1451E-01 | .1047 |
| 2 | .6966E-02 | .2331E-02 | .8646E-01 | .1451E-01 | .1047 |
| 3 | .6966E-02 | .2331E-02 | .8646E-01 | .1451E-01 | .1047 |
| 4 | .6966E-02 | .2331E-02 | .8646E-01 | .1451E-01 | .1047 |
| 5 | .69663-02 | .2331E-02 | .8646E-01 | .1451E-01 | .1047 |

Predator lengths by area

| Area | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pred 1 | 433.2 | 425.5 | 422.3 | 421.0 | 420.5 |
| 2 | 476.7 | 452.6 | 442.2 | 437.9 | 436.2 |
| 3 | 416.7 | 465.2 | 461.4 | 453.2 | 449.9 |
| 4 | 471.7 | 463.8 | 460.5 | 459.2 | 458.7 |
| 5 | 479.9 | 472.5 | 469.5 | 468.3 | 467.8 |

Eggs produced = .2057E+10

Juvenile predators:

| | | | | |
|---|---|---|---|---|
| .2057E+08 | .2057E+07 | .5143E+06 | .2057E+06 | .1029E+06 |
| .6172E+05 .0000 | .5555E+05 | .5277E+05 | .5224E+05 | .0000 |
| | .0000 | .0000 | .0000 | .0000 |

Juvenile predator lengths:

| | | | | |
|---|---|---|---|---|
| 95.73 | 159.2 | 213.1 | 259.0 | 298.1 |
| 331.3 | 359.5 | 383.5 | 403.9 | .0000 |
| .0000 | .0000 | .0000 | .0000 | .0000 |

| Time | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye | Flow | Temp | Efrt12 |
|---|---|---|---|---|---|---|---|---|
| 101.00 | 199. | .640E+05 | .207E+04 | .000 | .000 | .424E+09 | 7.25 | .000 |

| | | | | | |
|---|---|---|---|---|---|
| Gonad inc | .200E-02 | .200E-02 | .200E-02 | .200E-02 | .200E-02 |

| Prey | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|
| Area 1 | 1.347 | 763.0 | 12.73 | .0000 | .8159 |
| 2 | 236.4 | .1382E+06 | 1711. | .0000 | 99.31 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 3 | 323.3 | .1620E+06 | 2022. | .0000 | 117.3 |
| | 4 | 79.04 | .8851E+05 | 1052. | .0000 | 68.20 |
| | 5 | 14.76 | .5413E+05 | 620.9 | .0000 | 38.15 |
| **TotPsg** | | 772.6 | .6044E+06 | 7441. | .0000 | 498.2 |
| Pred Squaws | | | | | | |
| Area | 1 | 1707. | 682.7 | 273.1 | 109.2 | 43.69 |
| | 2 | .3946E+05 | .1578E+05 | 6314. | 2526. | 1010. |
| | 3 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 4 | 5017. | 2007. | 802.7 | 321.1 | 128.4 |
| | 5 | 517.2 | 206.9 | 82.75 | 33.10 | 13.24 |

| Cons | | Chin 0 | Chin 1 | Steelhd | Coho | Sockeye |
|---|---|---|---|---|---|---|
| **Squw** | **1** | 1.239 | 142.0 | 2.661 | .0000 | .4180 |
| | | 33.87 | 524.3 | 33.61 | .0000 | 10.47 |
| | | 8.110 | 1458. | 18.47 | .0000 | 2.461 |
| | | 5.244 | 269.5 | 6.063 | .0000 | 1.776 |
| | | .2481 | 214.0 | 2.833 | .0000 | .4416 |
| | **2** | .4955 | 56.78 | 1.065 | .0000 | .1672 |
| | | 13.55 | 209.7 | 13.44 | .0000 | 4.188 |
| | | 3.244 | 583.3 | 7.387 | .0000 | .9842 |
| | | 2.098 | 107.8 | 2.425 | .0000 | .7103 |
| | | .9925E-01 | 85.60 | 1.133 | 0000 | .1766 |
| | 3 | .1982 | 22.71 | .4258 | .0000 | .6688E-01 |
| | | 5.419 | 83.88 | 5.377 | 0000 | 1.675 |
| | | 1.298 | 233.3 | 2.955 | .0000 | .3937 |
| | | .8391 | 43.12 | .9702 | 0000 | .2841 |
| | | .3970E-01 | 34.24 | .4533 | .0000 | .7065E-01 |
| | 4 | .7928E-01 | 9.085 | .1703 | 0000 | .2675E-01 |
| | | 2.167 | 33.55 | 2.151 | .0000 | .6701 |
| | | .5190 | 93.33 | 1.182 | .0000 | .1575 |
| | | .3356 | 17.25 | .3881 | .0000 | .1137 |
| | | .1588E-01 | 13.70 | .1813 | 0000 | .2826E-01 |
| | 5 | .3171E-01 | 3.634 | .6813E-01 | .0000 | .1070E-01 |
| | | .8670 | 13.42 | .8603 | .0000 | .2681 |
| | | .2076 | 37.33 | .4728 | 0000 | .6299E-01 |
| | | .1343 | 6.899 | .1552 | .0000 | .4546E-01 |
| | | .6352E-02 | 5.478 | .7253E-01 | .0000 | .1130E-01 |
| mort | | | | | | |
| Area | 1 | .2645E-02 | .3874E-03 | .5900E-03 | 0000 | .1384E-02 |
| | 2 | .7231E-01 | .1431E-02 | .7450E-02 | .0000 | .3467E-01 |
| | 3 | .1731E-01 | .3980E-02 | .4094E-02 | 0000 | .8148E-02 |
| | 4 | .1120E-01 | .7355E-03 | .1344E-02 | .0000 | .5880E-02 |
| | 5 | .5298E-03 | .5841E-03 | .6281E-03 | 0000 | .1462E-02 |
| | T | .1040 | .7118E-02 | .1411E-01 | .0000 | .5155E-01 |

Per capita consumption by area

| Area | | 1 | 2 | -3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Pred | 1 | .4695E-02 | .2396E-02 | .8867E-01 | .2253E-01 | .1056 |
| | 2 | .4695E-02 | .2396E-02 | .8867E-01 | .2253E-01 | .1056 |
| | 3 | .4695E-02 | .2396E-02 | .8867E-01 | .2253E-01 | .1056 |
| | 4 | .4695E-02 | .2396E-02 | .8867E-01 | .2253E-01 | .1056 |
| | 5 | .4695E-02 | .2396E-02 | .8867E-01 | .2253E-01 | .1056 |

```
Predator lengths by area
Area          1           2           3           4           5
Pred 1    433.8       425.7       422.4       421.0       420.5
     2    481.8       455.7       443.5       438.4       436.3
     3    393.3       466.1       467.0       455.5       450.8
     4    476.2       467.3       461.9       459.7       458.9
     5    483.8       474.1       470.1       468.5       467.8

Eggs produced =    .2057E+10
Juvenile predators:
          .2057E+08   .2057E+07   .5143E+06   .2057E+06   1029E+06
                                  .5277E+05    5224E+05   : 0000
          : 6172E+05 0000  . .5555E+05 0000  . 0000  : 0000  . 0000

Juvenile predator lengths:
          95.92       159.3       213.3       259.2       298.2
          331.3       359.6       383.6       404.0       .0000
          . 0000      . 0000      .0000       .0000       .0000

Year:         1; No. juvenile cohorts:         9; Area1 dist. of
predators:
   3.300000E-02   7.630000E-01   9.700000E-02   9.700000E-02
   1.000000E-02
Elapsed time =    1337.870000 seconds
```